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A STUDY OF SANDSTONE MEMBERS OF THE JEFFERSON CITY AND COTTER FORMATIONS AT ROLLA, MISSOURI

OLIVER R. GRAWE AND JAMES S. CULLISON
School of Mines and Metallurgy, University of Missouri

ABSTRACT

This study was conducted primarily to establish petrographic criteria for distinguishing between the basal Cotter sandstone and the Jefferson City sandstones with which it is associated in the Rolla Quadrangle, Missouri. Texture is found to be a reliable criterion, especially when used in conjunction with field relationships, and texture analyses are applied in working out several local stratigraphic problems. Shape of grain and quantitative heavy mineral analyses are of no value in correlation but are made the basis of an interpretation of the geologic history of the sandstones. These rocks, originally composed of well-sorted and well-rounded grains, were derived largely from preexisting sediments and were deposited in a shallow sea. They subsequently were modified by ground water which brought about secondary enlargement of the quartz grains and introduced a group of sulphides similar to those which comprise the lead and zinc deposits of the state.

INTRODUCTION

A series of petrographic studies of the sandstones of the Ozark region has been initiated by the senior author. This paper treats of the petrography of certain sandstone members in the Jefferson City and Cotter formations. It was carried on primarily to establish criteria for the identification of the basal Cotter sandstone and the results have been applied by the junior author[1] in his revision of the Jefferson City formation in the Rolla Quadrangle, Missouri.

[1] J. S. Cullison, "Revision of the Jefferson City Formation in the Rolla Quadrangle, Missouri," a thesis submitted to the faculty of the School of Mines and Metallurgy of the University of Missouri in partial fulfilment of the requirements for the degree, Master of Science, May, 1930.

The problem was suggested by Dr. C. L. Dake, to whom the authors also are indebted for criticizing the manuscript and for reviewing the field evidence. They are grateful to Dr. G. A. Muilenburg for checking some of the heavy mineral identifications, and are indebted to the Missouri Bureau of Geology and Mines for transportation facilities. In laboratory routine they were assisted by W. H. Power and R. T. Wade.

REGIONAL STRATIGRAPHY

The Rolla Quadrangle, Missouri, is approximately 110 miles southwest of St. Louis, near the crest of the Ozark uplift. When Lee[1] mapped the geology of the quadrangle in 1912, all the dolomitic strata which lie beneath the Carboniferous outliers and above the Roubidoux formation were included in the Jefferson City. More recent studies by Ulrich have shown that the stratigraphy of this formation needs revision in the whole Ozark region. Some strata which were included in it on lithologic evidence are now known to have no equivalents in the type section at Jefferson City, Missouri. Beds in the Eureka Springs and Harrison quadrangles which Ulrich[2] had referred first to the Yellville limestone and then to the Jefferson City of Missouri subsequently were found by him to be younger than this formation and were mapped as Cotter and Powell by Purdue and Miser.[3] Similarly, strata in southeastern Missouri[4] which formerly were called Jefferson City now are known to represent three formations: the Jefferson City, restricted; the Cotter; and the Powell; and they have been so mapped in Ste Genevieve County by Weller and St. Clair.[5]

The need for a revision of the Jefferson City formation in the Rolla Quadrangle was suggested when Bridge and Charles[6] observed

[1] Wallace Lee, "The Geology of the Rolla Quadrangle," *Mo. Bur. Geol. and Mines*, 2d ser., Vol. XII (1913).

[2] A. H. Purdue and H. D. Miser, *U.S. Geol. Surv. Geol. Atlas, Eureka Springs-Harrison Folio, No. 202* (1916), p. 4.

[3] *Ibid.*, Areal Geology Sheet.

[4] H. F. Bain and E. O. Ulrich, "The Copper Deposits of Missouri," *U.S. Geol. Surv. Bull. 267* (1905), p. 12.

[5] Stuart Weller and Stuart St. Clair, "Geology of Ste Genevieve County, Missouri," *Mo. Bur. Geol. and Mines*, 2d ser., Vol. XXII (1928), p. 25.

[6] Josiah Bridge and B. E. Charles, "A Devonian Outlier near the Crest of the Ozark Uplift," *Jour. Geol.*, Vol. XXX (1922), p. 452.

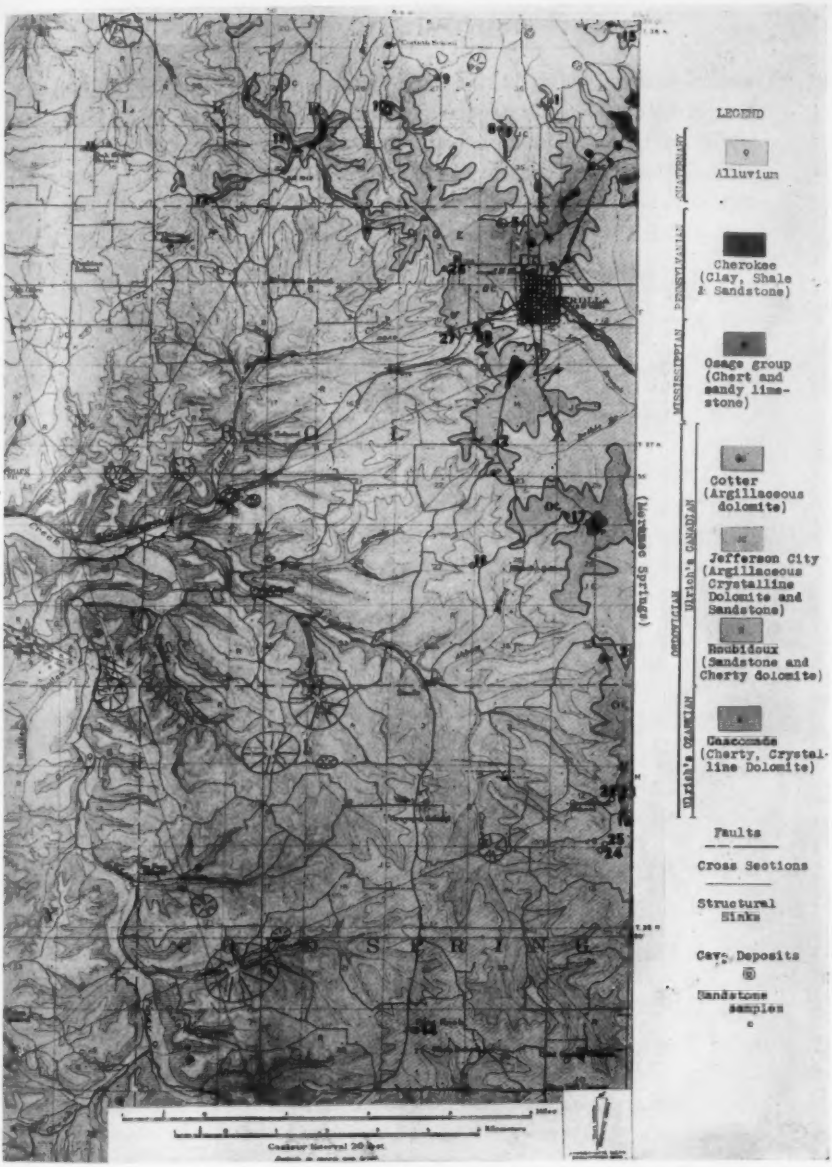


FIG. 1.—Areal distribution of the Cotter formation in the Rolla Quadrangle, Missouri

Geologic map of Wallace Lee used as a base (Wallace Lee, "The Geology of the Rolla Quadrangle," *Mo. Bur. Geol. and Mines*, 2d ser., Vol. XII [1913]).

several Cotter-like species of *Hormotoma* in chert of the upper part of the formation. These observations were strengthened in the spring of 1928, when Ulrich examined an outcrop of sandstone at Macedonia, $5\frac{1}{2}$ miles north of Rolla on U.S. Highway 63. After due consideration of the associated cherts, he called this sandstone the

TABLE I

PALEOZOIC SEQUENCE IN THE VICINITY OF ROLLA, MISSOURI

Pennsylvanian	
Cherokee (?)	
Unconformity	
Mississippian*	
Warsaw (?)	Residuum
Keokuk	
Burlington	
Fern Glen	
Unconformity	
Devonian†	
Grand Tower	
Unconformity	
Ordovician	
Canadian (Ulrich)	
Cotter	
Unconformity	
Jefferson City	
Unconformity (?)	
Roubidoux	
Unconformity	
Ozarkian (Ulrich)	
Gasconade	

* Josiah Bridge, "A Study of the Faunas of the Residual Mississippian of Phelps County (Central Ozark Region), Missouri," *Jour. Geol.*, Vol. XXV (1917), pp. 558–75.

† Josiah Bridge and B. C. Charles, "A Devonian Outlier near the Crest of the Ozark Uplift," *Jour. Geol.*, Vol. XXX (1922), p. 452.

base of the Cotter formation and referred the underlying dolomite to the true Jefferson City. In the fall of 1928, at the suggestion of Professor C. L. Dake, the junior author traced this basal sandstone south from Macedonia into the Rolla Quadrangle and found that it occurs below the *Hormotoma* zone of Bridge and Charles, and above the *Jeffersonia* horizon of the Jefferson City formation. The present study shows that this sandstone is sufficiently constant lithologically and stratigraphically to permit its use as a key horizon

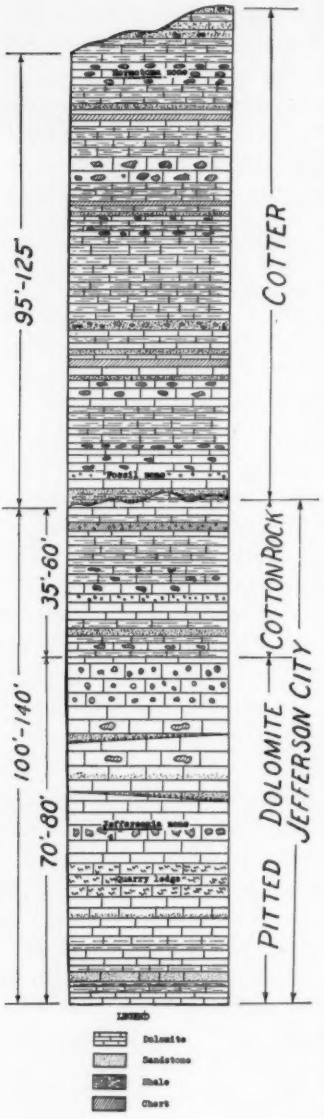
in tracing and mapping the Jefferson City-Cotter contact in the Rolla Quadrangle (Fig. 1). Thus, although the occurrence of typical Cotter fossils in the upper dolomitic strata is the primary basis for dividing the Jefferson City formation as mapped by Lee, the occurrence of a persistent sandstone below the faunal zone is the practical basis of division. Fossils may be found only in some of the more decayed chert and often are absent where most desired, but the sandstone is present wherever the base of the Cotter is exposed.

The stratigraphic relationships of the Jefferson City and Cotter formations as now known in the vicinity of Rolla are indicated in Table I. The Jefferson City beds overlie those of the Roubidoux and are separated from them by a break in sedimentation which probably is of no more significance than the breaks which occur within the formations themselves. The Cotter, in turn, lies unconformably upon the beds of the Jefferson City formation but this break also is only of diastemic importance. The big unconformity occurs at the top of the Cotter formation, the overlying sediments being either residual soil or outliers of Devonian or Carboniferous strata. Except in the northeastern and eastern parts of the quadrangle the Cotter has been eroded away entirely.

Both the Jefferson City and Cotter formations are composed chiefly of cherty dolomites. Sandstones are only of secondary importance (Fig. 2). The dolomites are of two types: one is gray, finely crystalline, and becomes pitted on weathering; the other is very fine-grained, drab, argillaceous, and locally is termed "cotton rock." The crystalline and more massive dolomite is most abundant in the lower part of the Jefferson City formation and has been designated the *pitted dolomite member* by Lee.[1] The more thinly bedded argillaceous dolomite is predominant in the upper part of the Jefferson City and throughout the Cotter formation and was called the *cotton rock member* by Lee.[2]

The sandstones which were studied in the present investigation are interbedded with these dolomites. The most important sandstone is the one at the base of the Cotter formation. It rests upon 4–18 inches of the greenish-blue to bluish-gray clay which occurs at the top of the Jefferson City formation (Secs. 1 and 2), and consists

[1] *Ibid.*, p. 36. [2] *Ibid.*, p. 38.



either of a single massive bed or of a series of thin beds separated by shale and by dolomite laminae. It occurs 75–115 feet above the so-called Quarry ledge[1] of the Jefferson City formation (Fig. 2) and about 95 feet below the *Hormotoma* zone mentioned by Bridge and Charles.[2] It also occurs 5–15 feet below a brownish fossiliferous dolomite but the fossils are preserved too poorly for identification. This sandstone may represent the same stratigraphic horizon as the sandstone which occurs at the base of the Cotter formation in Ste Genevieve County and which lies 30 feet below a white partly oölitic chert that carries a Swan Creek fauna.[3] If this correlation is correct, the basal Cotter sandstone at Rolla may be equiv-

[1] The Quarry Ledge is an easily recognized, finely granular, massive dolomite which is characterized by a peculiar coarsely pitted, pseudofucoidal surface. It is 5–7 feet thick and constitutes a valuable key horizon because it is prominently exposed and occurs persistently about 25 feet above the base of the Jefferson City formation.

[2] Josiah Bridge and B. E. Charles, *op. cit.*, p. 452.

[3] Stuart Weller and Stuart St. Clair, *op. cit.*, pp. 81–82.

FIG. 2.—Composite section of the Jefferson City and Cotter formations at Rolla, Missouri. Modified after Lee (Wallace Lee, "The Geology of the Rolla Quadrangle," *Mo. Bur. Geol. and Mines*, 2d ser., Vol. XII [1913], p. 37).

SECTION 1

SECTION OF COTTER AND JEFFERSON CITY FORMATIONS IN RAILROAD CUT ¼-MILE WEST OF ROLLA, SEC. 10 AND SEC. 11, T. 37 N., R. 8 W.

Cotter: Description	Thickness Feet
14. Cotton rock, buff, argillaceous, thinly-bedded	10
13. Cotton rock, buff to gray, arenaceous; with nodules of oölitic chert	2
12. Cotton rock, buff to white, very thinly bedded, interlaminated with thinner beds of bluish-gray shale and yellowish-brown to white sandstone (Sample No. 28*c*) and with white and gray banded chert lenses	3
11. Cotton rock, gray to buff, medium bedded	5
10. Breccia, containing pebbles of dolomite and angular fragments of white to gray porcelaneous chert cemented by a buff crystalline dolomite; somewhat oölitic, arenaceous, and fossiliferous	1
9. Cotton rock, buff to gray, thinly-bedded, interlaminated with numerous bluish-gray shale lenses and occasional thin yellowish-brown sandstone lenses	5
8. Dolomitic limestone, buff, light gray to white on fresh fracture, massive at base, more thinly bedded and siliceous toward the top	12
7. Sandstone, white, friable; contains thin flakes of bluish-gray shale (Sample No. 28*b*)	1
Total thickness of Cotter formation	39
Jefferson City:	
6. Shale, bluish-green to bluish-gray, contains numerous blue and white banded chert nodules near the top	1
5. Dolomitic limestone, light gray to white on fresh fracture, even, fine-grained, spalls off in plates at right angles to the bedding	2
4. Cotton rock, buff to gray, thinly bedded	2½
3. Oölite, gray to white, siliceous, interfingered with thin lenses of cotton rock	1½
2. Cotton rock, gray, medium-bedded, carries numerous pyrite crystals	2
1. Sandstone, gray to white, brownish on weathered surface, friable; grades upward into dolomite (Sample No. 28*a*)	4
Total thickness of Jefferson City formation	13

SECTION 2

SECTION OF COTTER AND JEFFERSON CITY FORMATIONS AT FAIR GROUND HILL, ¾-MILE WEST OF ROLLA ON U.S. HIGHWAY 66, SEC. 10, T. 37 N., R. 8 W.

	Description	Thickness Feet
Cotter:		
30.	Cotton rock, buff, argillaceous, thinly bedded	15
29.	Brecciated chert, interbedded with siliceous oölite	3
28.	Sandstone, fine-grained, friable, white (Sample No. 27)	2
	Total thickness of Cotter formation	20
Jefferson City:		
27.	Shale, thinly bedded, bluish-green to bluish-gray	1
26.	Cotton rock, buff, argillaceous	4
25.	Covered	14
24.	Cotton rock, buff, argillaceous, with chert nodules	2
23.	Cotton rock, light gray to buff, massive	4
22.	Cotton rock, buff, argillaceous, thinly bedded and interstratified with chert	5
21.	Cotton rock, light gray to buff, massive	3
20.	Cotton rock, light buff, thinly bedded	7
19.	Cotton rock, light gray to buff, massive	3
18.	Cotton rock, buff, thinly bedded	5
17.	Covered	5
16.	Dolomite, buff, argillaceous, pitted	5
15.	Dolomite, gray to buff with fossiliferous chert lenses and nodules	6
14.	Cotton rock, interbedded with white porcelaneous chert	4
13.	Cotton rock, interbedded with blue shale	2
12.	Dolomite, crystalline, gray to buff	3
11.	Covered, red residual soil with cellular, fossiliferous chert	3
10.	Dolomite, gray to yellow, argillaceous, pitted	2
9.	Dolomite, gray to yellow, argillaceous, pitted	2
8.	Dolomite, gray, arenaceous, massive	1
7.	Dolomite, crystalline, gray, massive, with quartz druses and seams of white calcite	12
6.	Dolomite, gray, arenaceous, contains chert lenses and quartz geodes	5
5.	Dolomite, gray to yellow, crystalline, interbedded with chert and cotton rock	5
4.	Dolomite, crystalline, buff, interbedded with cotton rock	2
3.	Chert, white, oölitic	1
2.	Dolomite, buff, arenaceous, interbedded with bluish shale	3
1.	Covered	6
	Total thickness of Jefferson City formation	115

alent to the middle of the Cotter in northern Arkansas, where the formation is 500 feet thick.

The most important sandstones in the Jefferson City formation are near its base. South of Rolla, in Sec. 27, T. 37 N., R. 8 W., an irregular, conglomeratic sandstone with a maximum thickness of 6 feet outcrops 15 feet above the Quarry Ledge. In the adjacent Meramec Springs Quadrangle a similar bed (Sample No. 18) occurs

TABLE II

JEFFERSON CITY SANDSTONES SAMPLED NEAR ROLLA, MISSOURI

Sample Number	Location	Elevation Feet	Remarks
14	SW. ¼, NW. ¼, Sec. 27, T. 36 N., R. 8 W.	1,230	Boulders on south slope of Pilot Knob, 45 feet above *Jeffersonia* horizon
18	NW. ¼, Sec. 30, T. 36 N., R. 7 W.	1,170	Ledge 1–2 feet thick and 12 feet above Quarry Ledge
20	SE. ¼, SW. ¼, Sec. 21, T. 37 N., R. 7 W.	1,100	.....
22	SW. ¼, NE. ¼, Sec. 12, T. 36 N., R. 8 W.	1,090	Massive beds on valley floor
23	SE. ¼, NE. ¼, Sec. 12, T. 36 N., R. 8 W.	1,130	Thin ledge above Sample No. 22
24*a*	NW. ¼, NE. ¼, Sec. 13, T. 36 N., R. 8 W.	1,130	Lowest ledge above last fork of valley
24*b*	NW. ¼, NE. ¼, Sec. 13, T. 36 N., R. 8 W.	1,140	Thin ledge 10 feet above Sample No. 24*a*
25	SW. ¼, SE. ¼, Sec. 12, T. 36 N., R. 8 W.	1,140	Boulders above Sample No. 24*b*
28*a*	NE. ¼, SE. ¼, Sec. 10, T. 37 N., R. 8 W.	1,090	Lowest ledge on southeast side of railroad cut west of Rolla

12 feet above the Quarry Ledge. North and west of Rolla another bed is exposed about 30 feet above this horizon. For the purposes of the present investigation only those beds which are in close proximity to the basal Cotter sandstone were studied in detail and their locations are given in Figure 1 and in Table II.

LITHOLOGY

The sandstones of both the Jefferson City and Cotter formations are typically thin and lenticular, and grade both laterally and vertically into dolomite. They commonly vary from a few feet to a few inches in thickness, and rapid variation within short distances has been noted. The basal Cotter sandstone is the most persistent but it, too,

varies in thickness from 12 feet in Sec. 24, T. 38 N., R. 8 W. to only 4 inches in Sec. 3, T. 37 N., R. 8 W. The thin beds are observed most commonly as slabs of float on the hillsides while the thick beds outcrop more prominently.

The sandstones are composed of medium to fine colorless quartz grains which usually are poorly cemented by silica, carbonates, and iron oxides. The unweathered rock is white or grayish, but in most outcrops this color has been changed to brown by limonite. The base of any member may contain angular and subangular fragments of chert and pebbles of dolomite, or it may display the cavities from which these fragments have been removed by weathering. This gives the rock a local conglomeratic or even brecciated appearance.

The sandstones usually are quite friable and porous, but in some places silicification has progressed far enough to produce quartzite. The cause of this local induration is not always apparent but in many cases it is related directly to the surface of weathering. The cement commonly is of two types: either glassy, crystalline silica, which has enlarged the sand grains causing them to interlock; or dense cherty silica, which has surrounded the sand grains and has incorporated them into lenses and into nodules. Gradations from friable sandstone into both types of highly indurated rock suggest that all the cement is secondary but enough study has not been devoted to the cherty phase to give it more than passing mention.

Locally the sandstones exhibit minor structures of shallow-water origin; such as, mud-cracks, cross bedding, and ripple marks of the current ripple type.

PETROGRAPHY

METHOD OF SAMPLING

Preliminary to making a petrographic study, an attempt was made to obtain representative samples of the sandstones. Each outcrop was cleared of surficial products of weathering and the freshest and most friable material was obtained. Where the exposure presented a definite outcrop face, as in a quarry or road cut, channel samples were taken. Where the outcrop consisted of slabs and blocks of float random sampling was employed. The size of the sample taken from each bed or slab was roughly proportional to the

thickness of that member in the outcrop, and each field sample weighed from 500 to 1,000 grams. Lumps rather than pulverized material were selected in order to minimize loss of fines by leakage through the cloth sample sacks.

LOCATION OF SAMPLES

The location of each sample is indicated by number in Figure 1, and an annotated list of these localities is given in Tables II and III.

PREPARATION OF SAMPLES FOR ANALYSIS

Each field sample was crushed on a hard maple board with a hard maple block. Crushing was continued until a binocular examination showed that disaggregation was practically complete. The sample was dried thoroughly by heat, then reduced to 200 grams by coning and quartering, and placed in tin containers to await sieving.

TEXTURE ANALYSES

The 200 gram samples were sieved through 8-inch Tyler standard double crimped screens having apertures closely conforming to the scale proposed by Wentworth.[1] A "Ro-Tap" shaker was used and sieving was continued for 16 minutes, the optimum time for complete separation as found by experiment. The sand remaining on each screen was weighed, and the weights were recalculated to distribute the inevitable loss on sieving proportionally among the several grades. The results are presented graphically in Figure 3.

From these analyses the textural constancy of the basal Cotter sandstone is apparent. Each histogram is characterized by a well-defined modal class, the $\frac{1}{4}$–$\frac{1}{8}$ mm. grade; by a low percentage of grains in the adjacent classes; by a higher percentage of grains in the coarse admixture than in the fine; and by a low textural range.

The Jefferson City sandstones are somewhat variable in texture. Their texture histograms are of two types: one is characterized by a well-defined modal class, the $\frac{1}{2}$–$\frac{1}{4}$ mm. grade, which is accompanied by a pronounced fine admixture; the other is characterized by a poorly defined modal class, the $\frac{1}{4}$–$\frac{1}{8}$ mm. grade, which is accompanied by a coarse admixture that is almost as pronounced as the

[1] C. K. Wentworth, "A Scale of Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. XXX (1922), p. 382.

TABLE III

BASAL COTTER SANDSTONES SAMPLED NEAR ROLLA, MISSOURI

Sample Number	Location	Elevation Feet	Remarks
1	NE. ¼, SE. ¼, Sec. 26, T. 38 N., R. 8 W.	1,020	
2	NW. ¼, NW. ¼, Sec. 23, T. 37 N., R. 8 W.	1,100	
3	NE. ¼, SE. ¼, Sec. 11, T. 38 N., R. 8 W.	970	
5	NW. ¼, NE. ¼, Sec. 2, T. 37 N., R. 8 W.	1,040	
6	N. ½, NE. ¼, Sec. 14, T. 38 N., R. 8 W.	980	
7	NW. ¼, SE. ¼, Sec. 14, T. 38 N., R. 8 W.	980	Sink structure on west side of U.S. Highway 63. Sample No. *7a*, lowest sandstone exposed on south side of sink. Sample No. *7b*, lowest sandstone exposed on north side of sink. Sample No. *7c*, sandstone in center of sink. Probably Pennsylvanian
8	SE. corner, SW. ¼, SW. ¼, Sec. 26, T. 38 N., R. 8 W.	1,020	
9	SE. ¼, NW. ¼, Sec. 27, T. 38 N., R. 8 W.	1,030	20 feet above roadfork on west road
10	NE. ¼, SE. ¼, Sec. 28, T. 38 N., R. 8 W.	1,020	
11	NW. ¼, NE. ¼, Sec. 32, T. 38 N., R. 8 W.	1,060	15 feet below fossiliferous dolomite ledge
12	SW. ¼, SE. ¼, Sec. 31, T. 38 N., R. 8 W.	1,070	Massive sandstone at road-fork
13	NE. ¼, NW. ¼, Sec. 29, T. 38 N., R. 7 W.	1,120	
15	SW. ¼, SE. ¼, Sec. 24, T. 38 N., R. 8 W.	1,030	12 feet of massive sandstone 5 feet below fossiliferous dolomite ledge
16	SE. ¼, NE. ¼, Sec. 27, T. 37 N., R. 8 W.	1,100	Residual boulders near road on west side of small knob
17	SW. ¼, SW. ¼, Sec. 24, T. 37 N., R. 8 W.	1,120	In creek bed 5 feet below fossiliferous dolomite ledge
19	NE. ¼, SE. ¼, Sec. 12, T. 36 N., R. 8 W.	1,130	
21	NE. ¼, SE. ¼, Sec. 36, T. 37 N., R. 8 W.	1,120	
26	SW. ¼, SE. ¼, Sec. 3, T. 37 N., R. 8 W.	1,060	Thin sandstone just above the junction of the two principal ravines and 5 feet below a fossiliferous dolomite ledge
27	NW. ¼, SE. ¼, Sec. 10, T. 37 N., R. 8 W.	1,100	Massive sandstone south side of road-cut west of the fair grounds
28	NE. ¼, SE. ¼, Sec. 10, T. 37 N., R. 8 W.	1,090	Sample No. $28b_1$, middle sandstone ledge at west end of railroad cut. Sample No. $28b_2$, same ledge as Sample No. $28b_1$ but at center of cut. Sample No. *28c*, thin sandstone lenses 24 feet above Sample No. $28b_2$

modal class itself. The majority of lower Jefferson City sandstones are of the second type and hence resemble the basal Cotter sandstone in texture. The majority of the topmost Jefferson City sandstones are of the first type and, hence, are distinctly coarser than those above or those below. This change may be due entirely to lenticular deposition by shifting currents or it may be an expression of the contraction of the Jefferson City sea which finally withdrew completely from the area.

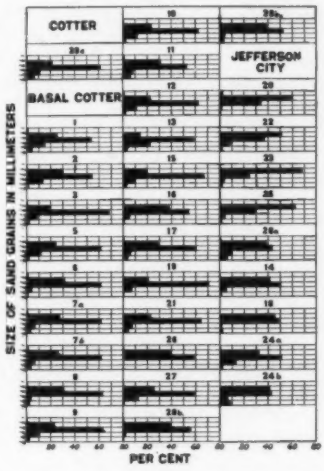


FIG. 3.—Texture histograms of Jefferson City and Cotter sandstones near Rolla, Missouri.

The sandstones of both formations are fairly well sorted. More than 95 per cent of the sand grains are concentrated in three grades, the modal class and the coarse and fine admixtures (Table IV and Fig. 4); and the grains are so well distributed among these grades that the arithmetic mean, the median, and the calculated mode are nearly identical and fall within the modal class (Table V). This compares favorably with the degree of sorting found in beach sands and is in agreement with field evidence which points toward a shallow-water marine origin for these sandstones.

The average basal Cotter sandstone seems to be better sorted than the average Jefferson City sandstone since the modal class of the former is more pronounced than that of the latter. The coefficient of uniformity has been used by Condra[1] and by others as a measure of the degree of sorting in sands. This constant is defined as "The ratio of the size of grain which has 60 per cent of the sample finer than itself to the size which has 10 per cent finer than itself."[2] These coefficients may be obtained directly from the ogives of Figure

[1] G. E. Condra, "Sand and Gravel Resources and Industries of Nebraska," *Nebraska Geol. Surv.*, Vol. III, Part I (1908), p. 30.

[2] *Op. cit.*

5 or they may be calculated from the original data. The uniformity coefficients calculated for the average basal Cotter and the average Jefferson City sandstones are 1.97 and 2.43 respectively. Since a perfectly sorted sand has a uniformity coefficient of 1, these calculations again show that the basal Cotter sandstone is, on the average, the better sorted one.

TABLE IV

AVERAGE TEXTURE ANALYSES OF SANDSTONE SAMPLES TAKEN NEAR ROLLA, MISSOURI

SIZE MM.	AVERAGE ANALYSES IN PER CENT	
	Average of 9 Jefferson City Sandstone Samples	Average of 22 Basal Cotter Sandstone Samples
2–1	0.00	0.01
1–$\frac{1}{2}$	0.70	0.70
$\frac{1}{2}$–$\frac{1}{4}$	49.22	27.48
$\frac{1}{4}$–$\frac{1}{8}$	40.42	60.50
$\frac{1}{8}$–$\frac{1}{16}$	6.38	8.68
—$\frac{1}{16}$	3.28	2.63
Total	100.00	100.00

The basal Cotter sandstone also is finer than the Jefferson City sandstones. This is indicated not only by the histograms of Figure 3 but also by the ogives of Figure 5. The curve representing the texture of the average Jefferson City sandstone is similar to that representing the texture of the average basal Cotter sandstone, but the latter is shifted to the right of the former or occurs on that side of the graph which represents the finer sizes. This difference in texture is indicated numerically by the various averages presented in Table V and by the difference in effective size. This has been defined[1] as that size which has 10 per cent of the grains smaller than itself and 90 per cent larger. The effective sizes

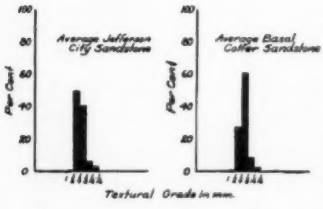


FIG. 4.—Texture histograms of the average Jefferson City and basal Cotter sandstones near Rolla, Missouri.

[1] G. E. Condra, *op. cit.*, p. 31.

of the average basal Cotter and average Jefferson City sandstones are 0.116 and 0.124 millimeters respectively. This difference in texture also may be expressed by designating these sandstones in accord with Wentworth's classification.[1] The basal Cotter is a fine sandstone, whereas the Jefferson City sands are medium or medium-fine sandstones.

SHAPE ANALYSES

The sand grains of each textural grade were examined under a binocular microscope to make certain that each sample had been disintegrated completely. At the same time, the characteristics of the grains themselves were noted.

TABLE V

AVERAGES OF TEXTURE ANALYSES OF SANDSTONE SAMPLES TAKEN NEAR ROLLA, MISSOURI

	Average of 9 Jefferson City Sandstone Samples	Average of 22 Basal Cotter Sandstone Samples
Modal class	$\frac{1}{12}$–$\frac{8}{12}$ mm.	$\frac{5}{12}$–$\frac{4}{12}$ mm.
Mode	$\frac{6}{12}$ mm.	$\frac{7}{12}$ mm.
Mean	$\frac{5}{12}$ mm.	$\frac{7}{12}$ mm.
Median	$\frac{6}{12}$ mm.	$\frac{7}{12}$ mm.

The quartz grains are predominantly angular and subangular (Fig. 6) chiefly due to the secondary development of crystal faces upon the original grains. Rhombohedral and striated prism faces are especially prominent on the small grains and many of these are doubly terminated. Why this development is more pronounced on the small grains than on the large may be an open question but perhaps it may be due simply to the fact that less silica is required to fill out the crystal structure of the small ones. The high angularity of the particles passing the $\frac{1}{16}$ mm. screen is clearly the result of grain fracturing, for this grade consists largely of quartz fragments and wood pulp from the crushing block.

Pitting and frosting of these quartz grains is due to the irregular deposition of silica and to the tearing apart of the grains during the bucking-down process. Wherever two grains are pulled apart pits and negative crystals result. Parts of some samples were so complete-

[1] C. K. Wentworth, *op. cit.*, p. 382.

ly intergrown and cemented that they could not be disintegrated and had to be discarded.

Petrographic examination of grains mounted in balsam and in oil showed that the quartz grains were round when deposited. Each grain consists of a round nucleus surrounded by crystalline quartz in optical continuity with it. The outline of the original grain is only faintly visible. Additional evidence that the original grains were round when deposited is furnished by Sample No. 19. Its grains are subround rather than angular and they have undergone very little secondary enlargement. Quite probably secondary growth is related to underground water circulation and to surface weathering.

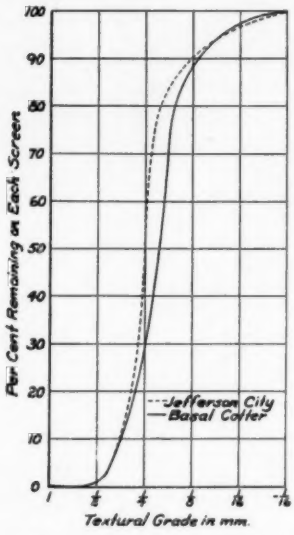


FIG. 5.—Cumulative frequency texture curves of the average Jefferson City and Cotter sandstones near Rolla, Missouri.

No differences in grain shapes were noted which might serve to distinguish the basal Cotter from the Jefferson City sandstones. All have undergone secondary silicification and in most cases this has enlarged the grains about 15 per cent.

HEAVY MINERAL ANALYSES

A representative group of 7 Jefferson City and 14 Cotter sandstone samples were separated with acetylene tetrabromide having a density of approximately 2.9. The separation was carried out in simple short-stemmed glass funnels equipped with rubber tubes and Hoffman pinch cocks of the improved type. Each textural grade was treated separately and the heavy minerals were determined by petrographic and microchemical methods. Eighteen minerals were identified with certainty and several were noted but could not be determined from the few grains available. The following list includes those which were noted.

Biotite.—Soft, brown, irregular micaceous cleavage flakes. Biaxial, negative with very small optic angle. Rare and usually observed only in the $\frac{1}{4}$ and $\frac{1}{8}$ mm. grades.

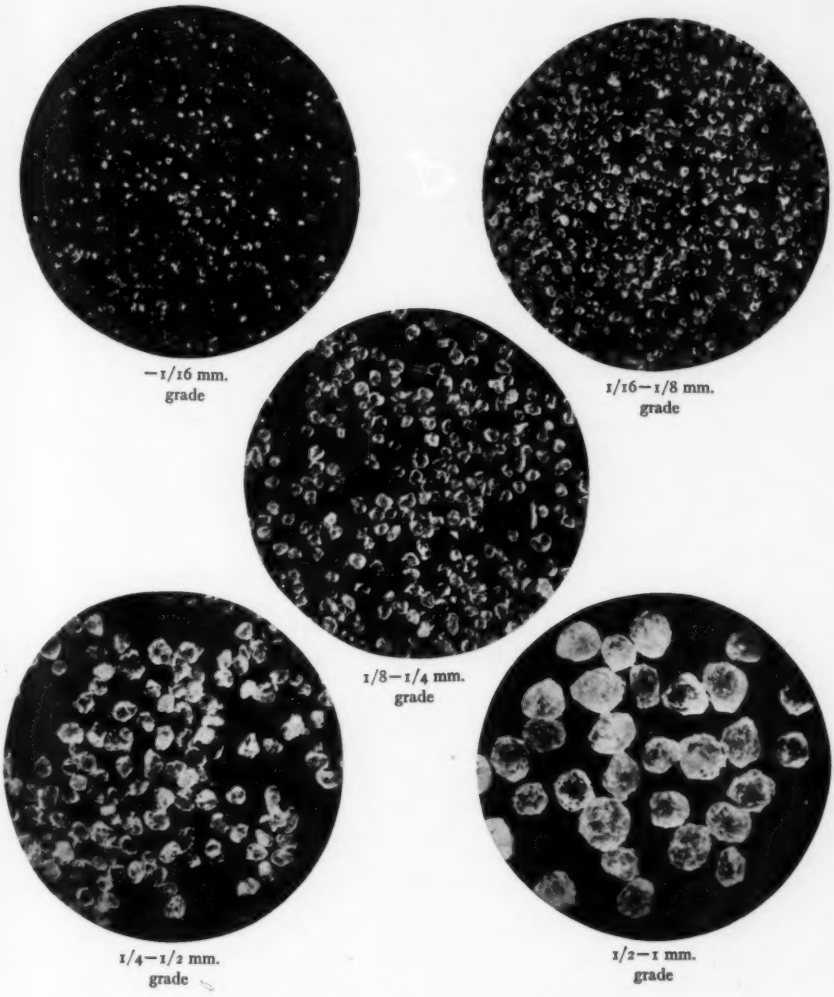


FIG. 6.—Sand grains from each textural grade of basal Cotter sandstone Sample No. 27

Chalcopyrite.—Brassy, golden-yellow, irregular flakes which give strong copper tests. Most common in the finest grade.

Chlorite.—Soft, green, irregular micaceous cleavage flakes, probably clinochlore. Rare and observed only in the coarse grades.

Dolomite.—White rhombohedral grains which effervesce only in hot dilute acid. Very rare.

Epidote.—Yellowish-green angular grains. Biaxial, negative with large optic angle, strong birefringence and having an index of refraction greater than 1.74. Very rare and observed only in a few samples of the basal Cotter sandstone.

Galena.—Unmistakable lead-gray cubes. Common in both sands.

Garnet.—Slightly reddish angular isotropic grains apparently having rhombic dodecahedral cleavage and conchoidal fracture. Only two grains were noted.

Hematite.—Earthy red and specular black grains which have the typical reddish-brown streak. Rare.

Hornblende.—Black angular grains possessing long prismatic cleavage faces. Biaxial, negative, marked green to brown pleochroism. Refractive index close to 1.635, extinction angle nearly 15°. Rare. Observed only in the coarse grades of some of the Jefferson City sandstone samples.

Leucoxene(?).—White and brownish, earthy, round opaque grains of doubtful composition. Tests for titanium were negative. Common in both formations.

Limonite.—Very abundant as a brown cement binding other minerals and as cubes pseudomorphous after pyrite.

Magnetite.—Black magnetic grains usually coated by limonite. May be ilmenite in part. Rare.

Malachite(?).—Round greenish grains which partly dissolve in dilute HCl and yield a decided copper test with $K_4Fe(CN)_6$. Probably disseminated in silica which does not dissolve.

Muscovite.—Irregular colorless flakes. Very rare.

Pyrite.—Brassy cubes and a few pyritohedrons are present in all grades of many samples. Altered to limonite in part.

Siderite.—Brown vitreous cement which effervesces freely in hot dilute HCl and gives a strong ferrous iron test.

Sphalerite.—Light yellow, transparent, angular grains with good cleavage. Isotropic, high refractive index. Not readily soluble in HCl but easily dissolved by HNO_3. Solutions react for zinc with $K_4Fe(CN)_6$. Common. Abundant in Sample No. 15.

Tourmaline.—Black, brown, olive-green, blue, and colorless well-rounded grains, usually elongate but many are nearly spherical. Uniaxial, negative, refractive index of approximately 1.635. Yield green boron flame with $KHSO_4$. Colorless varieties resemble colorless zircon but the two can be distinguished easily by the fact that tourmaline floats in methylene iodide but zircon does not. Occurs in all grades below $\frac{1}{4}$ mm. but is most abundant in the $\frac{1}{8}$ mm. and $\frac{1}{16}$ mm. grades. Most abundant of all heavy minerals, blue and colorless grains are rare.

Tremolite.—White or colorless, transparent, angular grains with good prismatic cleavage and uneven fracture. Biaxial, negative, refractive index approximately 1.635, extinction angle 10°–17°. Observed in only the coarse sizes of a few Jefferson City samples. Rare.

Zircon.—Colorless or slightly rose, well-rounded and subrounded spherical and elongate grains. A few grains exhibit geniculate twinning and the very smallest grains still possess traces of crystal faces. Uniaxial, positive, high relief, high refractive index, strong birefringence. Most abundant in the fraction which passes through the $\frac{1}{16}$ mm. sieve. Occurs occasionally in the coarse grades of the Jefferson City sandstones but usually is confined to the fine grades of the Cotter sandstones. Abundant.

The mineral abundance was determined by actually counting all the grains in each textural grade. Each sample was spread along a crease in a card and the grains of each mineral were counted as they were passed under a binocular microscope. Six typical analyses are given in Table VI.

Comparison of these analyses leads to the conclusion that heavy minerals cannot be used in correlating the Jefferson City and Cotter sandstones. Those minerals which seem to be present in a single formation occur too infrequently, and those which are persistent occur to the same extent in both formations. None is of diagnostic value. This is in agreement with the conclusion reached by Cordry[1] in his study of the Roubidoux and other sandstones of the Ozark region.

With the data presented in Tables V and VI the absolute abundance of the heavy minerals can be estimated with fair accuracy. If the sandstones are assumed to be composed of perfectly spherical grains, the total number of grains, N, in any sample can be calculated from the formula:

$$N = \frac{W}{\frac{4}{3}\pi r^3 d},$$

where W is the weight of the sample in grams, r is the radius of the average grain in centimeters, and d is the density of the grain material. The analyses of Table VI are based on 200-gram samples in which the average quartz grain had a radius of approximately $\frac{1}{80}$ centimeter (Table V) and a density of 2.65 grams per cubic centimeter. Substitution of these figures in the above formula yields a value

[1] C. D. Cordry, "Heavy Minerals in the Roubidoux and Other Sandstones of the Ozark Region, Missouri," *Jour. Paleont.*, Vol. III (1929), p. 82.

TABLE VI

NUMBER OF HEAVY MINERAL GRAINS IN 200-GRAM SAMPLES OF JEFFERSON CITY AND COTTER SANDSTONES NEAR ROLLA, MISSOURI

MINERAL	TEXTURE GRADES																							
	Jefferson City												Basal Cotter											
	14				18				28a				6				15				27			
	¼	⅛	1/16	−1/16	¼	⅛	1/16	−1/16	¼	⅛	1/16	−1/16	¼	⅛	1/16	−1/16	¼	⅛	1/16	−1/16	¼	⅛	1/16	−1/16
Biotite	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	1	1	....	....	....	....	....
Chalcopyrite	....	....	8	52	1	5	13	31	....	2	3	21	Included with pyrite								....	....	....	400
Chlorite	....	....	....	....	....	....	....	....	....	....	1	....	....	3	....	....	2	5	1	15	....	....	....	....
Galena	....	....	1	....	7	52	35	64	....	1	....	....	2	14	12	6	3	19	48	220	2	....	....	2
Hornblende	....	....	....	....	1	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Leucoxene	....	2	2	3	....	18	....	....	....	16	278	15	3	13	19	3	....	31	62	95	....	2	4	27
Pyrite	....	2	2	....	4	12	3	12	8	87	177	18	....	20	18	13	9	71	118	1,707	2	1	1	....
Sphalerite	....	....	....	....	....	4	....	....	....	....	1	....	1	11	17	2	19	76	142	734	2	....	25	....
Tourmaline	....	177	175	95	....	637	47	7	....	97	1,996	22	....	119	152	20	....	145	834	1,518	....	264	855	752
Tremolite	....	....	....	....	7	21	12	12	....	....	3	1	....	....	....	....	....	....	....	....	....	....	....	....
Zircon	....	16	20	98	....	....	52	16	....	2	42	168	....	....	18	66	....	....	8	1,685	....	8	22	389

for N of more than 9,200,000 grains. On this basis the grain counts of Table VI were calculated in per cent. The results may not be numerically exact but at least they give the order of abundance of the heavy minerals in the sandstones.

The two analyses of Table VII were selected because they represent the limits of variation in total heavy mineral content among the samples studied. By chance, both are analyses of the basal Cotter sandstone. Sample No. 6, obtained from the outcrop pro-

TABLE VII

ABSOLUTE ABUNDANCE OF HEAVY MINERAL GRAINS IN THE JEFFERSON CITY AND COTTER SANDSTONES NEAR ROLLA, MISSOURI

MINERAL	TOTAL NUMBER OF GRAINS		ABSOLUTE ABUNDANCE PER CENT	
	Sample No. 6	Sample No. 15	Sample No. 6	Sample No. 15
Biotite	0	2	0.00000	0.00002
Chlorite	3	23	.00003	.00025
Galena	34	290	.00037	.00315
Leucoxene	38	188	.00041	.00204
Pyrite and Chalcopyrite	51	1,905	.00055	.0207
Sphalerite	31	971	.00034	.0105
Tourmaline	291	2,497	.00316	.0271
Zircon	84	1,693	.00091	.0184
Total	532	7,569	0.0058	0.0822

nounced basal Cotter by Ulrich, contains the smallest number of grains, and Sample No. 15, obtained two miles south of the key outcrop, contains the largest number of grains.

The total heavy mineral content of the Jefferson City and Cotter sandstones is small, varying from 0.005 to 0.1 per cent. The most abundant mineral, tourmaline, constitutes only 0.003–0.03 per cent of the sandstone and minerals such as galena, heretofore designated common, are present only to the extent of 0.0003–0.003 per cent.

It is interesting to note that these results are of the same order of magnitude as those published by Winslow and Robertson,[1] who made detailed chemical analyses of a number of dolomites of the Ozark region. The rocks analyzed by them contained: 0.00041–

[1] Arthur Winslow and J. D. Robertson, "Lead and Zinc, II," *Mo. Geol. Surv.*, Vol. VII (1894), p. 480.

0.00156 per cent lead, 0.00016–0.01528 per cent zinc, and 0.0004–0.00256 per cent copper. The order of abundance of these metals seems to be the same in dolomites and sandstones.

CONCLUSIONS

APPLICATION TO GEOLOGIC MAPPING

Detailed study of the basal Cotter and associated Jefferson City sandstones shows that neither field nor laboratory criteria alone can always be used to differentiate between these sandstones. Careful mapping of the Jefferson City–Cotter contact requires that these studies be used to supplement one another.

The most important field criteria for the recognition of the basal Cotter sandstone are:

1. Its occurrence 75–115 feet above the Quarry Ledge of the Jefferson City formation and 5–15 feet below a fossiliferous brown dolomite.

2. Its occurrence directly above a bluish-green to bluish-gray shale.

3. Its occurrence below the bluish-gray and brown, banded and oölitic chert, typical of the Cotter formation and above the white porcelaneous chert of the Jefferson City formation.

4. Its occurrence below typical Cotter fossils and above typical Jefferson City fossils.

The one characteristic of the basal sandstone itself which can be used as a criterion for identification is texture. The basal Cotter sandstone is finer grained and better sorted than the Jefferson City sandstones and its texture is remarkably constant within the area studied. In many instances it alone can be used to discriminate between the basal Cotter and the Jefferson City sandstones. Texture is particularly diagnostic when used in conjunction with field criteria and has been found useful especially in those areas where sink structures occur or where exposures are meager and mapping must be based largely on float.

Texture analyses were applied in working out a sink structure on Highway 63, $5\frac{1}{2}$ miles north of Rolla (Fig. 7). Since the local Pennsylvanian sediments typically occur in sinks, all of the sandstone in this outcrop was considered to be of that age, but close ex-

amination revealed that in this sink are two sandstones separated by a cherty zone. Texture analyses of three samples (Samples No. 7*a*, No. 7*b*, No. 7*c*) taken across the outcrop clearly show that the two samples obtained beneath the cherty mass represent the same horizon and that it is quite different from the one occupying

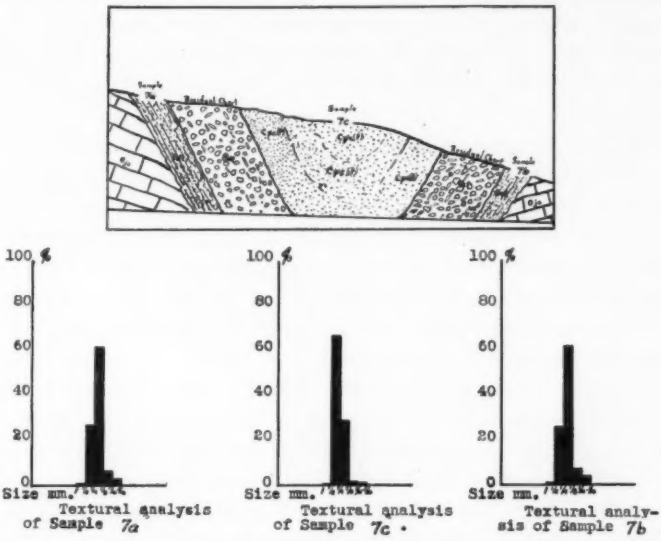


FIG. 7.—Diagrammatic sketch of sink structure 5½ miles north of Rolla, Missouri, on U.S. Highway 63; and texture histograms of sandstone samples taken across the outcrop.

the center of the structure. Comparison of these analyses with those already made (Fig. 3) shows that the outer sandstone is basal Cotter. This deduction is supported by field evidence, for the sandstone pronounced basal Cotter by Ulrich is exposed on the next hill north. Not enough work has been done on the central sandstone to determine its age but field evidence suggests that it is Pennsylvanian.

Near the top of Pilot Knob in the NW. ¼ of Sec. 27, T. 36 N., R. 8 W., a large number of sandstone blocks occupy the south slope. Their high topographic position, 1,230 feet, and their massive structure suggest that they are Cotter or Pennsylvanian in age but, since

their texture (Sample No. 14) is more like that of Jefferson City sandstone, a re-study of the area was made. This led to the discovery of a *Jeffersonia* fauna only 45 feet down the hillside. The conclusion reached is that the blocks at the top of Pilot Knob belong to the Jefferson City formation and that the Jefferson City-Roubidoux contact as mapped by Lee,[1] is incorrect. The high topographic elevation of the *Jeffersonia* horizon may be due to faulting. A fault with a throw of about 50 feet has been mapped by Lee one mile south of Pilot Knob and it is likely that others occur in the immediate vicinity.

Another application of this study to geologic mapping is illustrated in determining the Jefferson City-Cotter contact in the railroad cut, ½-mile west of Rolla (Sec. 1). Two similar sandstones occur within 9 feet of one another but the upper member (Sample No. 28*b*) is thought to be the basal Cotter sandstone because it rests upon a bluish-green shale and has a texture which more closely resembles the basal Cotter member than does the sandstone below (Sample No. 28*a*).

GEOLOGIC HISTORY

The foregoing field and laboratory studies permit an interpretation of the geologic history of the sandstones of the Cotter and Jefferson City formations. The presence of marine fossils in the chert of the associated dolomites; the argillaceous and arenaceous character of these dolomites; the presence of minor breaks in sedimentation, particularly the one marking the contact of the two formations; the conglomeratic and brecciated basal phase of the sandstones themselves; and the common occurrence of mud-cracks, cross bedding and ripple marks of the current ripple type, all point toward a shallow-water marine site of deposition for these sandstones.

This interpretation from field evidence is supported by petrographic study. Texture and shape analyses show that the sandstones were well sorted and well rounded when deposited, the degree of sorting and rounding being analogous to that found in modern beach sands. Heavy mineral analyses suggest that perhaps both sorting and rounding were inherited from pre-existing sediments, for 99 per cent of the detrital heavy mineral grains are exceedingly

[1] Wallace Lee, *op. cit.*, geologic map.

well rounded and it is doubtful whether such a character could have been produced in a single erosion cycle.

Two distinctly different types of heavy minerals are present. One group consists of distinctly detrital minerals which are genetically connected with the origin of the sandstones; the other group probably is not of detrital origin and comprises the common sulphide ore minerals of Missouri. It may be connected genetically with the lead and zinc deposits of the state. The heavy minerals may be classified as:

A. Detrital minerals:
   1. Round, resistant grains of leucoxene, tourmaline, and zircon.
   2. Angular, less resistant grains of biotite, chlorite, epidote, hornblende, and tremolite.

B. Non-detrital minerals:
   1. Sulphides; chalcopyrite, galena, pyrite, and sphalerite.
   2. Oxidation products; hematite, limonite, siderite, and a secondary green copper mineral, probably malachite in silica.

The presence of two distinctly different suites of detrital minerals indicates that perhaps all the sand grains did not come from the same source. Although 99 per cent of these grains are round resistant leucoxene, tourmaline, and zircon, there is a small percentage of angular, less resistant grains of biotite, chlorite, epidote, hornblende and tremolite. The former are found chiefly in the fine textural grades while the latter are present in the coarse textural grades. This suggests that the round grains have passed through more than one erosional cycle, whereas the angular grains have passed through only one erosion cycle or, if they have passed through more than one, they are still very close to their site of origin. The angularity of these grains might be accounted for by their good cleavage, but their freshness and the very presence of the minerals themselves strongly indicate that these grains were not derived from the same ultimate source as the rounded ones.

It also is of interest to note that apparently fresh feldspar grains, chiefly microcline and acid plagioclase, have been detected in the light fraction of the $\frac{1}{16}$ mm. and $-\frac{1}{16}$ mm. grades. These, too, may not be far removed from their parent rock.

The occurrence of chalcopyrite, galena, and sphalerite is interest-

ing but not unusual for the central Ozark region. McQueen[1] has found that sphalerite is particularly noticeable in the insoluble residues of the lower Cotter dolomites and small quantities of these minerals are concentrated locally. According to Lee,[2] concentration has taken place along synclinal axes, which suggests that the occurrence of these sulphides is genetically related to underground water circulation controlled by structure. That underground water has been active in depositing mineral matter is well illustrated by the secondary enlargement of the quartz grains and by the development of crystal faces upon them. That the sulphide minerals were deposited after the deposition and consolidation of the sandstones seems to be the logical conclusion and, since the suite of sulphide minerals in the sandstones is the same as that in the lead and zinc deposits of the state, it is quite probable that the two are related genetically.

The summary conclusion drawn is that the Jefferson City and Cotter sandstones in the vicinity of Rolla, Missouri, were derived largely from pre-existing sediments, but local material, probably sedimentary, may have contributed to a small extent. The original grains were deposited in a shallow sea close to the shore and, especially during the deposition of the basal Cotter sandstone, the conditions of sedimentation were so uniform throughout the area that the uniform texture may now be used to supplement field observations in tracing this member. Subsequent to deposition and consolidation, the sandstones have been modified by ground water which has brought about the secondary crystallization, enlargement, and intergrowth of the quartz grains, and has introduced the same group of sulphide minerals as is found in the lead and zinc deposits of the state.

[1] H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Mo. Bur. Geol. and Mines, Fifty-sixth Biennial Rept.* (1931), Appendix I (1929), p. 24.

[2] Wallace Lee, *op. cit.*, p. 101.

ANORTHOSITE IN LOS ANGELES COUNTY, CALIFORNIA

WILLIAM J. MILLER
University of California at Los Angeles

ABSTRACT

The purpose of this paper is to describe and attempt to explain the structure and origin of a large occurrence of anorthosite in Los Angeles County, California. Several theories of the origin of anorthosite advocated by petrologists are considered in their application to the occurrence, and comparisons are made with anorthosites of other regions.

INTRODUCTION

One of the most important results of the writer's field work in the San Gabriel Mountains of California during the last six years has been the mapping of a large, heretofore practically unknown body of anorthosite. Geologic literature seems to contain no reference to any other occurrence of anorthosite in the United States west of the Rocky Mountains. With the exception of a brief abstract recently published by the writer,[1] the only reference to this anorthosite in the literature is that by Hershey,[2] who collected some specimens by the railroad along the northern margin of the area. These were submitted to A. C. Lawson who found the feldspar to be andesine, and who found one specimen to be hornblende-diorite and three others to "bear the same relation to diorite that anorthosites do to gabbro."

Because of its exceptional composition among the plutonic rocks, being made up very largely of the single mineral plagioclase, the origin of anorthosite has long been a puzzle to students of igneous rocks. During the last twelve years occurrences of anorthosite in northern New York, Southeastern Canada, and Minnesota have been rather elaborately studied by several petrologists, including the writer whose particular interest has been centered upon the extensive areas in the Adirondack Mountains. Various hypotheses in regard to the genesis of the anorthosite have been set forth by these petrologists. The finding of the extensive area of anorthosite and

[1] *Bull. Geol. Soc. Amer.*, Vol. XXXIX (1928), pp. 164–65.

[2] O. H. Hershey, *Amer. Geol.*, Vol. XXIX (1902), pp. 284–86.

its genetically related facies in Los Angeles County has renewed the writer's interest in the whole problem, with a result that new light has been thrown upon it.

LOCATION AND EXTENT OF THE ANORTHOSITE

The anorthosite proper, with closely associated gabbroic and dioritic facies, occupies a practically unbroken area comprising a considerable part of the western San Gabriel Mountains in central Los Angeles County. The greatest length of the area is 18 miles, from east to west. Its greatest width is 8 miles, from north to south. Extensive Tertiary strata are sharply down-faulted against the anorthosite along the western and northwestern sides of its outcropping area so that its full extent is not known. It is possible, though not probable, that the anorthosite may extend a great many miles westward under cover of the Tertiary. To the north and northwest, however, it cannot extend more than a few miles, as proved by the widespread development of crystalline rocks free from anorthosite within a few miles in those directions.

Lying just northeast of the large body of anorthosite, and cut off from it by a broad intrusive tongue of granodiorite, there is an area of 25 or 30 square miles of dark dioritic and metadioritic rocks cut to pieces by large and small masses of granodiorite. No true anorthosite was seen in this area which extends over the northeastern part of the Tujunga quadrangle and to the San Andreas fault system in the northwestern part of the Rock Creek quadrangle. This diorite is believed to be older than the anorthosite.

FACIES OF THE ANORTHOSITE

General statement.—There are many interesting facies of the anorthosite varying from almost pure, bluish-gray to white, coarse-grained plagioclase (mainly andesine) through gabbroic and dioritic anorthosite and ilmenite-rich gabbro and diorite to almost pure titaniferous magnetite. These facies are not sharply separated from each other, and the delimitation of several facies on the accompanying map is intended to be only a rough attempt to indicate the broader areal relations of these facies, numerous minor variations being entirely disregarded. The different facies are quite certainly variants of a single plutonic body.

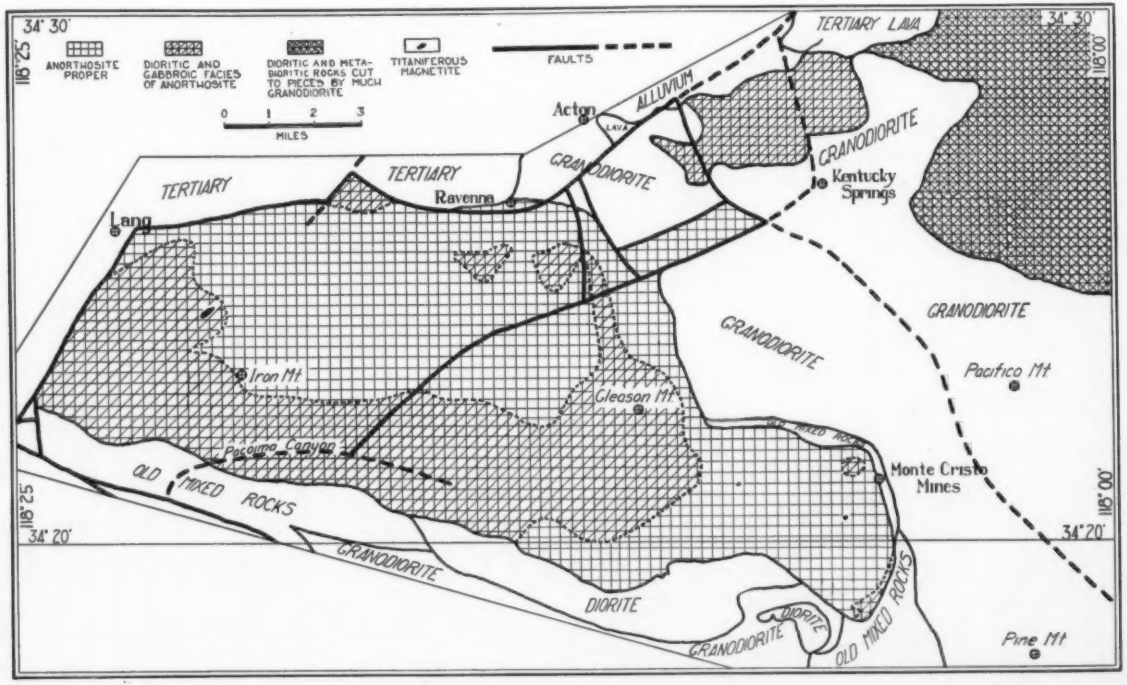


FIG. 1—Geologic map showing the anorthosite body in Los Angeles County, California, and its relation to adjacent formations

Anorthosite proper.—The anorthosite proper is so called because it consists very largely of plagioclase feldspar, that is to say, 90 per cent or more of plagioclase. In most cases the plagioclase content is more than 95 per cent. The color is white, bluish-gray, or light gray. Most of the rock is medium to coarse grained with crystals commonly ranging in size from $\frac{1}{8}$ to $\frac{1}{2}$ inch, and less commonly from 1 to 3 inches long. Most of the specimens examined show little or no granulation, but some bear considerable evidence of this texture. A foliated structure of even a moderate degree is rarely observable in the anorthosite proper.

Although the variations above mentioned are not sharply separated from each other, nevertheless there are often considerable areas of the bluish-white anorthosite as over against the nearly white, and areas of the coarser grained as over against the medium grained. Often, however, such variations are extremely local and irregular. The bluish-gray variety of the anorthosite is somewhat more extensive than the white variety.

A study of the feldspar in a dozen thin sections of the anorthosite proper from widely scattered localities revealed two facts; first, that it is is all plagioclase ranging from oligoclase to labradorite, with andesine greatly predominant; and, second, that the plagioclase of the white variety is in general somewhat more acidic than that of the bluish-gray variety. Most of the thin sections contain, in addition to the plagioclase, two or more of the following minerals in amounts ranging from 0 to 2 per cent: augite, biotite, magnetite, muscovite, apatite, and epidote. In addition to these, small quantities of either pyrite, calcite (secondary), hypersthene, zircon, or titanite were observed in some thin sections of the bluish-gray variety.

Dioritic and gabbroic facies.—There is a considerable range in mineralogical composition and texture of the rocks described in this category, but they are quite certainly facies of the anorthosite. The plagioclase content varies from over 80 per cent to none at all. It ranges from oligoclase to labradorite, but most of it is andesine. The other most abundant minerals are common hornblende, monoclinic pyroxene, biotite, and magnetite. Small amounts of apatite, titanite, or pyrite often show in thin sections, and much more locally there may be 10–20 per cent of either garnet or olivine. There is

generally little or no granulation of these rocks, though local exceptions are not uncommon. Most of these rocks are medium to moderately coarse grained, with not a few restricted localities in which the crystals are from 1 to 3 inches long. Foliation is seldom an evident structure.

Magnetite-rich facies.—Many very local, irregularly distributed portions of the gabbroic and dioritic facies of the anorthosite body are rich in magnetite. In such cases the magnetite often constitutes 10–40 per cent of the rock. The mineral is irregularly scattered through the rock in masses ranging in size from small grains to several inches across. Much more rarely masses of magnetite up to several inches across may be seen inclosed within almost pure plagioclase anorthosite.

Three small areas, so rich in magnetite that they have been called "ore bodies," are represented on the accompanying map. All of these areas have been staked out as mining claims. In each case the magnetite is notably titaniferous. A good example is the ore body 1 mile southwest of Monte Cristo Mines. It contains masses up to several rods across of almost pure titaniferous magnetite. Close to the magnetite they are crudely defined, dark-green crystals of hornblende with excellent cleavages. There are also medium- to moderately coarse-grained, bluish-gray, nearly pure plagioclase facies of anorthosite. The transition from the ore body to the anorthosite takes place within a few feet.

DISTRIBUTION OF THE FACIES

The above-described facies of the anorthosite are, as a rule, not at all sharply separated from each other. Thus the boundaries between the dioritic and gabbroic facies and the anorthosite proper are more or less arbitrarily represented on the accompanying map, but, in a general way, the principal areas occur as indicated on the map. Masses of dioritic or gabbroic anorthosite, without sharp boundaries, sometimes occur within the larger area of the anorthosite proper. Most of these are too small to be mapped. Masses of true anorthosite not rarely occur without sharp boundaries within the areas of dioritic and gabbroic anorthosite, but no attempt has been made to map these separately.

In Aliso Canyon $2\frac{3}{4}$ miles southeast of Acton a coarse-grained

dioritic facies of the anorthosite is cut by an inch-wide dike of nearly pure-white, medium- to fairly coarse-grained anorthosite, this dike no doubt representing a slightly later offshoot of the general anorthosite magma.

Both the relation of the facies to each other and their distribution are very irregular, as shown on the map. Although the anorthosite area is exceedingly rugged, with numerous altitude variations of thousands of feet, nevertheless there is no indication that the darker facies, as a whole, occupy a position above or below that of the anorthosite proper. There is, furthermore, no real indication that one facies in general occupies an outer or border position with reference to the other facies.

RELATION OF THE ANORTHOSITE TO OTHER ROCKS

The principal rocks of the region older than the anorthosite are a metasedimentary series, a metadiorite, and a granite, the first two having been more or less intricately cut and injected by the granite. These rocks together with the anorthosite are Paleozoic or pre-Cambrian in age, probably the latter.

The principal crystalline rocks younger than the anorthosite are a generally massive quartz diorite and a still later, extensively developed granodiorite, probably of Jurassic age. Still younger are dikes of aplite, pegmatite, and silexite which seem to be genetically related to the granodiorite. Youngest of all are small, scattering dikes of porphyrite and diabase, the latter of Tertiary age.

STRUCTURE OF THE ANORTHOSITE

The great body of true anorthosite, together with its gabbroic and dioritic facies, is remarkably massive. The little foliation which does occur here and there is believed to be largely a magmatic flow-structure produced during a late stage in the consolidation of the magma.

The general trend of the anorthosite body and its facies is parallel to the general west-northwest trend and strike of foliation of the other older crystalline rocks of the San Gabriel Mountains.

The only formation which is both older than, and in contact with, the body of true anorthosite and its facies is the banded gneiss made up of metasedimentary rocks, metadiorite, and granite and con-

stituting the main bulk of the extensively developed mixed rocks mapped as the San Gabriel formation by the writer. The narrow belt of this banded gneiss bordering the anorthosite from southeast of Monte Cristo Mines to near Gleason Mountain shows strong dips away from the anorthosite. From Barley Flats to the southeastern border of the anorthosite the strike of foliation of the old banded gneiss swings around from west-northwest to about north-south adjacent to the anorthosite where the latter cross-cuts the foliation of the gneiss. The prominent belt of similar banded gneiss bordering the anorthosite on its southwestern side shows evidence of having been subjected to great pressure at right angles to the contact with the anorthosite. Not only are the dips steep, but also, as in Pacoima Canyon, closely pinched, almost isoclinal folds occur in the gneiss. All three of the structures just described as occurring in the old banded gneiss adjacent to the anorthosite are believed to have resulted from the shouldering action of the anorthosite or anorthosite-gabbro magma during its invasion of the old gneiss.

The above-mentioned evidence is against the conception of the anorthosite body as a great sill such as has been recently advocated by Grout[1] for the anorthosite-gabbro at Pigeon Point, Minnesota, or still more recently by Balk[2] for the Adirondack anorthosite. The evidence seems, rather, to be favorable to a batholithic, inverted cone-shaped, or thick-set laccolithic structure of the anorthosite body. Either of these modes of emplacement would have produced the strong shouldering action on the country rocks which the anorthosite invaded. The fact that various dikes of the distinctly later granodiorite cut parts of the anorthosite even at considerable distances within the margins of the latter seems to indicate an intrusive body whose marginal portions are considerably thinner than its interior. An inverted cone-shaped or a laccolithic structure, therefore, better harmonizes with the field facts than a batholith whose diameter increases with depth.

ORIGIN AND MODE OF EMPLACEMENT OF THE ANORTHOSITE

The best-known field evidence points to the following conclusions:

[1] F. F. Grout, *Bull. Geol. Soc. Amer.*, Vol. XXXIX (1928), pp. 555–62.

[2] R. Balk, *Jour. Geol.*, Vol. XXXVIII (1930), pp. 289–303.

1. The anorthosite, including its gabbroic and dioritic facies, is a true intrusive body, as proved by inclusions of old schist in it; dikes of anorthosite in the adjacent country rocks; and deformation of the older country rocks adjacent to the anorthosite.

2. The intrusive body is in the shape of either a laccolith or a cone-shaped batholith as strongly suggested by the fact that dikes of the distinctly later granodiorite cut outer portions of the anorthosite.

3. The original magma from which the facies of the anorthosite were derived was gabbroid in composition, this being about the average composition of all of the facies.

4. The original gabbroid magma differentiated very irregularly, possibly somewhat below the present position of the facies, into the various facies, and following this differentiation there was more or less movement before final consolidation of the differentiated magma, as shown by the facts that dikes of nearly pure anorthosite cut the older rocks, that inclusions were enveloped by the purer anorthosite, and that the invaded rocks were deformed by the differentiated magma.

5. The anorthosite entered the older rocks in a remarkably clean-cut manner, as shown by the absence of dikes except near the contacts, by the scarcity or lack of inclusions throughout most of the anorthosite, and by the lack of contact or assimilative action upon the invaded rocks.

Instead of part of the process just mentioned, gabbroic and dioritic material may have developed either by ordinary differentiation in the original magma, or by settling of mafic crystals into the lower portion of the magmatic chamber after which the mafic differentiate may have been forced upward into the upper-level purer anorthosite by a "later eruptive effort" as suggested by Daly.[1] Evidence for or against such a process is not conclusive, but the gradation between the plagioclase-rich and mafic facies, and the general lack of intrusive contacts, are facts unfavorable to this hypothesis. It is possible, however, that mafic facies of the anorthosite may have intruded the purer anorthosite while the latter was still very hot or partially molten, and hence have merged into it in wide zones.

[1] R. A. Daly, *Igneous Rocks and Their Origin* (1914), p. 327.

COMPARISON WITH OTHER REGIONS

Adirondack Mountains.—In the Adirondack Mountains of New York anorthosite occupies an almost unbroken area of 1,200 square miles, a smaller area of nearly 100 square miles, and various much smaller outlying areas. This anorthosite is younger than the Grenville series and distinctly older than the syenite-granite series of the Adirondacks, there being many dikes of syenite and granite in the anorthosite.

There are two rather clearly recognizable facies of the anorthosite: one which is very coarse grained, light to dark bluish-gray, and consists very largely of plagioclase (usually 90–98 per cent) varying from oligoclase to labradorite, with the latter predominant; and the other, which is usually a medium-grained, light-gray, moderately gneissoid rock consisting mainly of white plagioclase (chiefly labradorite) together with 5–15 per cent of mafic minerals. The latter seems to be an upper and outer border facies of the former.

Two important hypotheses in regard to the Adirondack anorthosite have been advocated and elaborately discussed. One of these is by Bowen, and the other by the writer. Bowen's hypothesis[1] may be very concisely stated as follows: (1) intrusion of a gabbroid magma in the form of a laccolith; (2) development of an upper, chilled, gabbroid border facies; (3) settling of mafic crystals in the magma to form gabbro and peridotite at the bottom; (4) settling of plagioclase crystals to form anorthosite above the gabbro; (5) solidification of residual syenite-granite magma in a position between the anorthosite and the upper chilled border.

The writer's hypothesis[2] may be very concisely stated as follows: (1) intrusion of a gabbroid magma in the form of a laccolith; (2) development of an upper and outer chilled, gabbroid, border facies; (3) probable settling of mafic crystals to form gabbro and peridotite at the bottom. (4) solidification of the residual plagioclase-rich magma to form a large body of anorthosite between the gabbro and the chilled border.

It is evident that the two hypotheses above outlined are similar in certain particulars and very different in others. According to

[1] N. L. Bowen, *Jour. Geol.*, Vol. XXV (1917), pp. 209–43; 500–512.

[2] *Op. cit.*, pp. 399–462; *Amer. Jour. Sci.*, Vol. XVIII (1929), pp. 383–400.

Bowen, the great body of syenite-granite developed directly from the intruded gabbroid magma, while, according to the writer, the syenite-granite is distinctly later and clearly intrudes the anorthosite. Detailed evidence in support of this conclusion is given in the writer's two papers on Adirondack anorthosite already cited. Cushing[1] has also maintained the conclusion that the syenite-granite series of the Adirondacks is distinctly younger than the anorthosite.

In view of the fact that no gabbro or peridotite is positively known to underlie the anorthosite, the writer[2] has suggested a reasonable modification of his hypothesis to the effect that the whole body of Adirondack anorthosite as now exposed, with its chilled border facies and its local variations to anorthosite-gabbro, may represent differentiation of the original gabbroid magma essentially *in situ*, followed by more or less magmatic movement before final consolidation. These and many other matters are rather elaborately discussed in the four papers cited previously.

A comparison of the anorthosite of the San Gabriel Mountains with that of the Adirondack Mountains shows that in the former:

1. The plagioclase is distinctly more acidic on the average.
2. There is a whitish variety, but it is more acidic than the bluish-gray variety.
3. The white variety is not a border (upper and outer) facies.
4. The mafic (gabbroic and dioritic) facies are more abundantly developed.
5. The various facies are even more irregular in their relation to each other.
6. Granulation (protoclastic) and foliation (magmatic flow-structure) are considerably less evident in the main body of the anorthosite, thus indicating less of the late magmatic movement than in the Adirondack anorthosite.
7. Distinctly younger granodiorite, instead of syenite-granite, clearly cuts the anorthosite. This granodiorite is younger than a quartz diorite which also cuts the anorthosite.
8. There is no evidence of the development of an assimilation product resulting from the action of either the diorite or granodiorite

[1] H. P. Cushing, *Jour. Geol.*, Vol. XXV (1917), pp. 506–7.

[2] *Amer. Jour. Sci.*, Vol. XVIII (1929), pp. 383–400.

intrusive upon still hot anorthosite and corresponding to the writer's so-called "Keene gneiss" of the Adirondacks.

9. Dikes of nearly pure plagioclase-anorthosite cut adjacent older rocks much as they do in the Adirondacks.

In view of the known facts, therefore, Bowen's hypothesis, involving the conception of a "residual syenite-granite magma," cannot be applied to the anorthosite of the San Gabriel Mountains. The many facts seem to harmonize far better with the writer's hypothesis, more particularly with its modified form as above outlined.

Very recently Balk has published a paper[1] on the Adirondack anorthosite. He accepts the conclusions of Bowen in part only, and his conception of a sill-like intrusion of the anorthosite is somewhat similar to that advocated by Grout (stated later in this article). According to Balk,[2] "gabbro, anorthosite, and syenite series are considered closely related consanguineous members of a common parent magma. . . . . The magma is believed to have risen from the southern edge of the Canadian Shield obliquely to the south." He also states that "most gabbros are ball-like or spheroidal resting on saucer-shaped foliated anorthosite like an egg in a nest."

It is difficult to discuss Balk's paper, not only because he makes no mention of the writer's observations and conclusions which have been elaborately set forth in various papers, particularly in two of them,[3] but also because various conclusions are supported by so little concrete field evidence. The writer understands, however, that Balk's theory is based upon numerous field observations, especially on the orientation of joints, schlieren, and flow-structures. It is to be hoped that this material will soon be published for the benefit of petrologists. Meantime, a few comments may be made indicating that Balk's theory may not be applied to the Los Angeles County anorthosite. Evidence against a sill-like mode of occurrence of the last-named anorthosite is presented under the next caption; there are no transition rocks between this anorthosite and more acidic (syenitic and granitic) rocks, but there is a distinctly younger grano-

[1] *Loc. cit.* [2] *Ibid.*, p. 289.

[3] W. J. Miller, *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), pp. 399–462; *Amer. Jour. Sci.*, Vol. XVIII (1929), pp. 383–400.

diorite; and the gabbro-diorite associated with this anorthosite does not occur in ball-like or spheroidal masses, but it everywhere grades into the anorthosite.

Pigeon Point, Minnesota.—The hypothesis advocated by Grout[1] to explain the anorthosite-gabbro at Pigeon Point, Minnesota, may be very briefly outlined as follows:

1. Intrusion of basaltic magma in the form of a sill 500 feet thick.
2. Development of a chilled diabasic border at both top and bottom of the sill.
3. Rise of phenocrysts from the main body of the magma to form a zone of gabbro grading into anorthosite-gabbro and small masses of true anorthosite.
4. Development of much diabase-gabbro in the lower part of the sill (above the lower chilled border) by settling of crystals or some other process, leaving a much thinner zone of acidic magma above it.
5. Solidification of the acidic magma to form a relatively thin zone of granite grading downward through intermediate rock into the gabbro, and lying just below the anorthosite-gabbro.

Among the reasons why Grout's hypothesis will not explain the anorthosite of the San Gabriel Mountains are the following: the anorthosite body, including its mafic facies, is not in the form of a sill with chilled borders at the top and the bottom; comparatively pure plagioclase-anorthosite is relatively far more abundant as a facies than it is on Pigeon Point; there is no zone of anorthosite-gabbro and anorthosite just under an upper chilled border; and there is no zone of granite grading downward into gabbro in the lower part of the intrusive body.

Bengal, India.—An important occurrence of anorthosite near Raniganj in Bengal, India, has been very recently discussed by Chatterjee.[2] In an area of about 4 square miles the anorthosite, with gradations into gabbroic and dioritic facies, is cut by norite dikes, and this combination is cut by dikes of distinctly later granite. Chatterjee considers the hypothesis proposed by Bowen and also that proposed by the present writer in their possible application to the Raniganj anorthosite. He states that "the intrusive

[1] *Op. cit.*, pp. 555–57.

[2] S. C. Chatterjee, *Quar. Jour. Geol. Soc. India*, Vol. II (1929), pp. 65–86.

granite body has no genetic relationship either with the norite or with the anorthosite. It is thus clear that originally the anorthositic mass of the Raniganj coal fields was formed in the way suggested by Miller."

Laramie Mountains, Wyoming.—Very recently an important contribution to the anorthosite problem has been made by Fowler[1] in a paper on the anorthosite of the Laramie Mountains, Wyoming. This anorthosite occupies an elongate area of several hundred square miles. Convincing evidence is presented to show that the anorthosite was intruded as a true magma into a series of highly folded pre-Cambrian schists in the form of a cone-shaped mass with thin edges in its upper portion. Xenoliths occur in the anorthosite. Gabbro masses, often rich in magnetite, occur in the anorthosite. These grade into the anorthosite, and they are regarded as differentiates of it essentially *in situ*. There are also small lenses of titaniferous magnetite in the form of differentiates of the anorthosite. Granite almost completely surrounds the anorthosite, and it has very plainly intruded the latter, there being no transition rocks from anorthosite through syenite to granite in any such sense as advocated by Bowen or Balk. The foliation of the old schist conforms to the margins of the anorthosite. Cataclastic textures occur near the margins of the anorthosite, and protoclastic textures well within it. All evidence, therefore, indicates that "the anorthosite moved upwards as a deep-seated basic intrusive into the overlying rocks."[2]

The Laramie anorthosite and its structural relations are, in nearly all important respects, remarkably like not only the anorthosite of the Thirteenth Lake region in the Adirondack Mountains, recently described by the writer,[3] but also in most ways very much like the anorthosite of Los Angeles County. Fowler's proof for the true intrusive character of the Laramie anorthosite as such and for the absence of a "residual syenite-granite magma" are surprisingly like those previously advocated by the writer for the Thirteenth Lake anorthosite, and now advocated by him for the Los Angeles County anorthosite.

[1] K. S. Fowler, *Amer. Jour. Sci.*, Vol. XIX (1930), pp. 305–15 and 373–403.

[2] *Ibid.*, p. 403.

[3] *Amer. Jour. Sci.*, Vol. XVIII (1929), pp. 383–400.

GENERAL CONCLUSION

It is an important fact that Bowen, Balk, Cushing, Grout, Chatterjee, Fowler, and the writer all believe that the anorthosite in each of the five widely separated regions—Adirondack Mountains, Pigeon Point, Raniganj, Laramie Mountains, and San Gabriel Mountains—was derived from a gabbroid magma. In regard to the form of the intrusion, and the place and manner in which it differentiated, several hypotheses have been advocated, the ideas of the writer agreeing to a considerable extent with those of Bowen, and to an unknown extent with those of Balk, while Cushing's, Chatterjee's, and Fowler's main conceptions are largely or almost wholly in agreement with those of the writer. Grout's hypothesis is in this respect distinctly different.

A principal point of disagreement lies in the relation of the granite of each region to the anorthosite. Bowen, Balk, and Grout contend that the granite was developed from a gabbroid magma after the intrusion of the latter, while Cushing, Chatterjee, Fowler, and the writer have presented strong evidence in support of the view that the granite is a distinctly later and separate intrusion in each of the regions they studied.

Each of the five anorthosite bodies above mentioned exhibits somewhat distinctive features, and it may well be that the anorthosite was developed under more or less different conditions in the several regions. All things considered, the writer's hypothesis, which is similar to that advocated by him for the Adirondack anorthosite, seems more satisfactorily to account for the origin and emplacement of the anorthosite of Los Angeles County than do the hypotheses advocated by Bowen and Balk.

GLACIAL TROUGHS OF THE CONTINENTAL SHELVES[1]

FRANCIS P. SHEPARD
University of Illinois

ABSTRACT

Submarine valleys may be classified into three groups. One group resembles youthful river valleys, another fault grabens, and a third glacial troughs. There are many reasons for believing that the valleys of this last group have been shaped by glacial excavation. They are found exclusively off glaciated coasts. They contain the deep-rimmed depressions, trough-shape, and relatively straight walls characteristic of glacially excavated valleys. Evidence of the presence of moraines within these shelf-troughs has been discovered. Finally the continental shelves off glaciated coasts are much deeper on the average than those off unglaciated areas.

INTRODUCTION

There are literally hundreds of submarine valleys extending out from the various coasts of the world. There are enough soundings in the vicinity of many of these valleys to give a rough idea of their general character. The study of the charts of these valleys has made it seem probable to the writer that there are at least three distinct types. One type has much in common with deep youthful river-cut valleys of the land. Most of the examples under this head are situated off large rivers or off the abandoned channels of large rivers. A second group resembles the grabens or rift valleys of the continents and are found principally off such unstable coasts as Japan and California. The third type is similar to glacially excavated valleys on land and occur, so far as could be determined, exclusively off glaciated coasts. For convenience these will be spoken of as "river-valley," "graben," and "glacial-trough" types, although it is to be understood that their origin is not necessarily to be inferred from the name.

CHARACTERISTICS OF GLACIAL TROUGH TYPE

The present paper will treat principally with the glacial-trough type which has the following characteristics distinguishing these valleys from the other types.

1. A trough shape, i.e., relatively steep walls and a broad base.
2. Undulating longitudinal profile.

[1] Presented in part before the Association of American Geographers.

3. Depths in the inner portions of the valleys comparable with or greater than the depths in the outer valleys.

4. Valley sides that are relatively straight or smoothly curving.

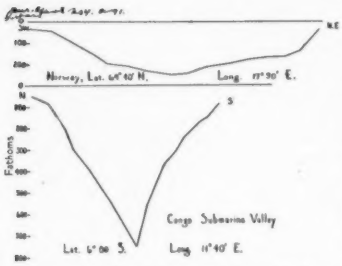


FIG. 1.—Transverse profiles showing the contrast between typical "river-valley" (lower) and "glacial-trough" (upper) submarine valleys.

These characteristics serve to distinguish this group from the other types of submarine valleys. For example, the striking difference in transverse profile of the river-valley type and glacial-trough type is shown in Figure 1. Figure 2 shows the same contrast as regards longitudinal profiles. The river-valley type grades outward, although admittedly not quite so continuously in all cases as in that shown. While the glacial-trough types appear to terminate at the edge of the continental shelf or even inside, the river-valley type generally extends well down the continental slopes. The graben types are broad and steep-

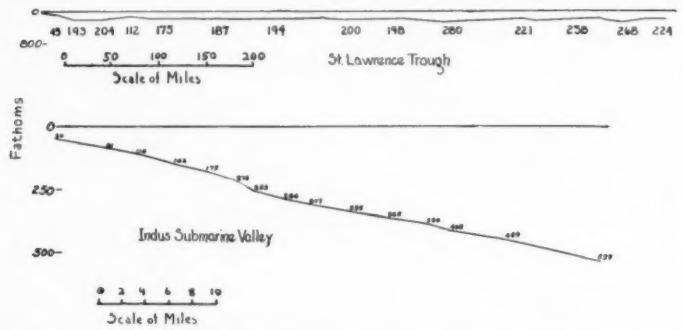


FIG. 2.—Longitudinal profiles showing the contrast between a "river-valley" (lower) and a "glacial-trough" submarine valley (upper).

sided like the glacial troughs, but unlike them extend into the deep parts of the ocean. Also the graben types are bordered by features suggestive of horsts (Fig. 3).

DISTRIBUTION

Figure 4 shows the location of the glacial-trough types. In some cases the soundings were not numerous enough to be certain that the troughs had all the characteristics which have been indicated above. Accordingly the map was prepared to differentiate between clear cases, probable cases, and possible cases. There are examples of the troughs off all the glaciated continental coasts of the world. There are also examples around several islands, notably Iceland. There are some indications of the troughs around Greenland despite the fact that the soundings are far less numerous than around Iceland. Antarctica has still fewer soundings, but again there are some suggestions of troughs in the deep continental shelf which surrounds it. It is so evident that shelves off glaciated coasts have an abundance of these troughs and that shelves off unglaciated coasts lack them that their origin would seem to be clearly connected with glaciation.

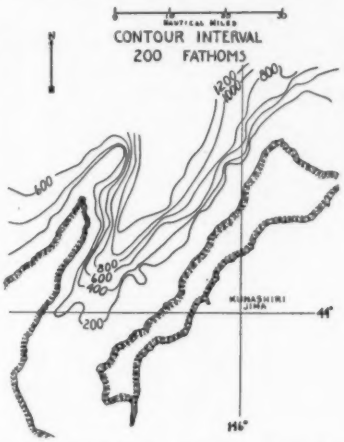


FIG. 3.—A "graben" type of submarine valley off the coast of Japan. Source, U.S. Hydrographic Chart No. 2424.

RELATION TO FIORDS

Most of the glacial-trough submarine valleys are seaward continuations of estuaries. Most of these estuaries are fiords. Nansen noted examples of this relationship off the coast of Norway.[1] The fiords of Alaska also extend into shelf-troughs in many places. Almost all of the fiords of Iceland have these features beyond them.

The troughs are generally wider than the fiords with which they connect (Fig. 5). In some cases several fiords form one shelf-trough.

[1] Fridjof Nansen, *"Bathymetrical Features of the North Polar Seas," Norw. North Polar Expedition, Scientific Results*, Vol. IV, No. 13.

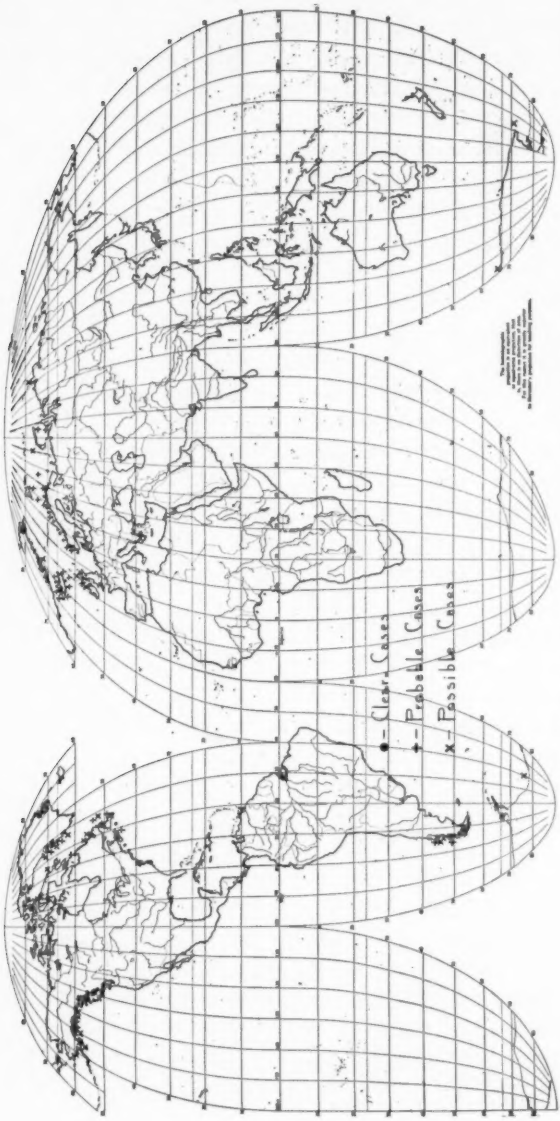


FIG. 4.—Showing the location of "glacial-trough" submarine valleys

In other cases the troughs divide seaward into two or more branches (Fig. 6). Where the fiords enter somewhat diagonally to the coast following structural trends, the troughs may continue in the same

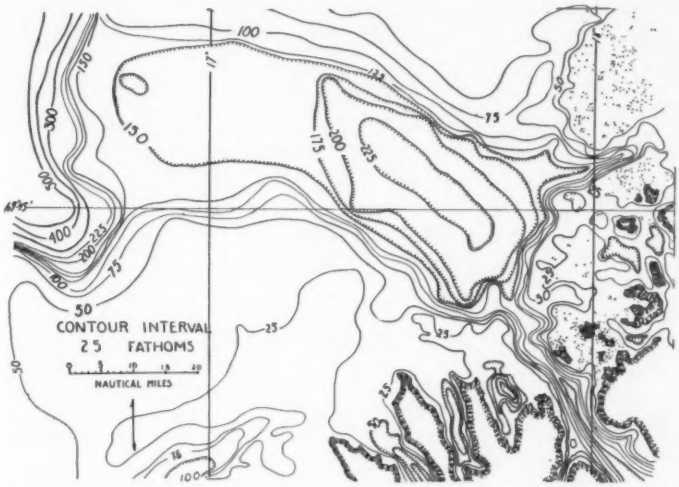


FIG. 5.—A "glacial trough" along the coast of Norway with greater width than the fiords inside. Source, British Admiralty Chart 2313.

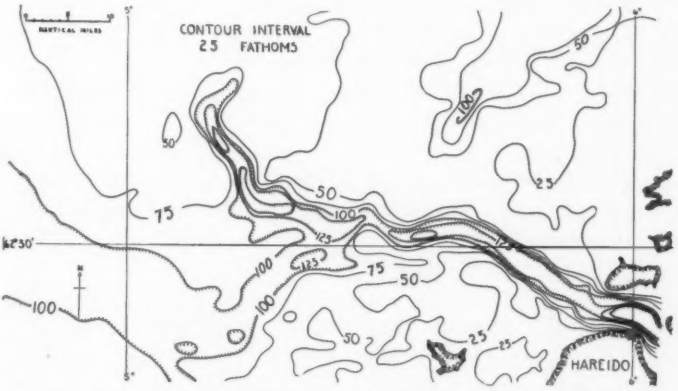


FIG. 6.—An example of a "glacial trough" which branches seaward. Source, British Admiralty Chart 2305.

direction (Fig. 7). In other places the diagonal fiords are continued by troughs transverse to the coast. So far as the writer knows there is only one case of a fiord which continues seaward as a river type of

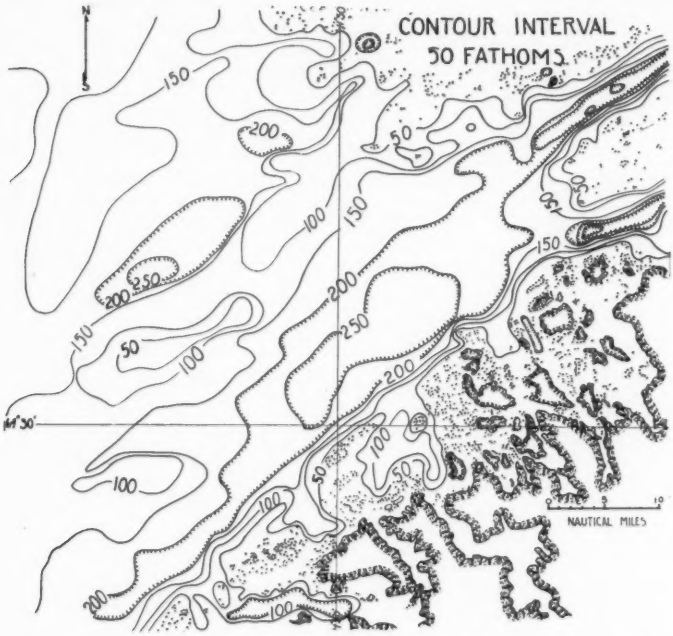


FIG. 7.—A "glacial trough" which follows the structural trend of the Norwegian coast. Source, British Admiralty Chart 2308.

submarine valley. This case is the well-known submarine valley off the Hudson at New York.[1] Since the location of this feature is outside the southeast margin of the terminal moraine of the great ice sheet it is not very significant.

In other cases the estuaries inside the troughs are not true fiords, but have the same deep water as fiords and other features in common with them such as hanging valleys on the side and deep-

[1] The lower Hudson is referred to as a fiord by D. W. Johnson in *The New England Acadian Shoreline*, p. 101.

rimmed depressions.[1] These estuaries are in character an intermediate step between fiords and shelf-troughs. The features along the Norwegian coast show practically every gradation between the three. In some cases the intermediate estuary grades into a fiord inland and into a shelf-trough outside. A rather special case is shown

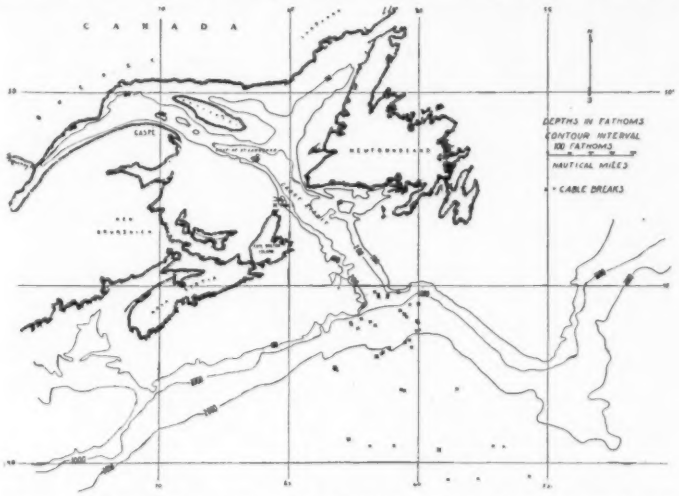


FIG. 8.—Illustrating the landward termination of the St. Lawrence trough at the juncture with the Saguenay fiord shows also the positions where cables were broken in the Grand Banks earthquake. Source, U.S. Hydrographic Chart 1412.

by the trough which comes out of the Gulf of St. Lawrence[2] (Fig. 8). The inner terminus of the deep part of the Gulf is at the point where the Saguenay, a typical fiord, enters. It seems significant that the trough which extends through the Gulf, and out to the edge of the continental shelf beyond, first shows its characteristics where this fiord comes into it.

GLACIAL FEATURES OF THE TROUGHS

Rimmed depressions.—As has been indicated already, the troughs have various features suggestive of glacial influence. Of these the

[1] F. P. Shepard, "Fundian Faults or Fundian Glaciers," *Bull. Geol. Soc. Am.*, Vol. XLI, p. 671.

[2] "The St. Lawrence (Cabot Strait) Submarine Trough" (to be published).

deep-rimmed depressions are perhaps the most impressive. While glaciers are the most common cause of rimmed depressions in valleys, they are also formed in other ways. However, if some of the other causes account for the numerous depressions in the troughs, it is difficult to see why these depressions are inconspicuous or absent in the submarine valleys on the shelves off unglaciated areas. In the

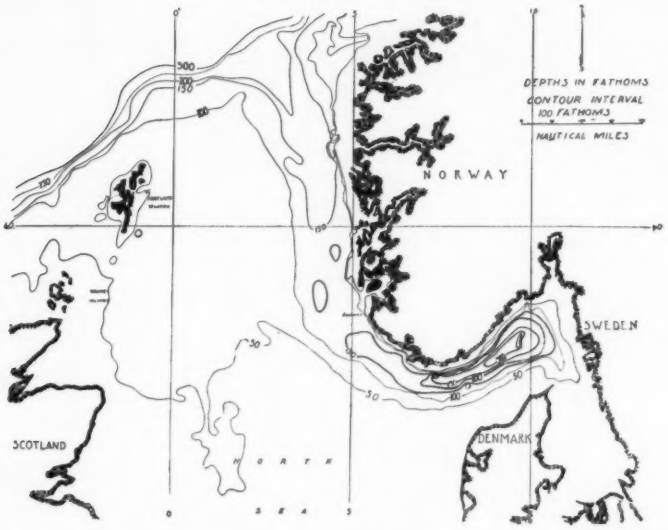


FIG. 9.—The south Norwegian submarine trough showing a large depression. Source, U.S. Hydrographic Charts 4840 and 4843.

troughs off glaciated coasts the depressions are both common and deep. Some of them would form lakes almost as large and fully as deep as the Great Lakes if the sea level were to be lowered to their rims. Figure 9 shows an example off the southern coast of Norway where a large potential lake exists.

Transverse profiles compared with fiords.—Profiles were drawn across many of the shelf-troughs and across many fiords in order to compare the two types. While it is evident that there are differences as regards steepness and height of the sides, the troughs have a general similarity to the fiords. This is found to be particularly the

case in comparing the troughs with the outer portions of the wider fiords. Figure 10 shows examples all drawn to the same scale. As stated previously the submarine valleys outside of the glaciated areas have an altogether different type of cross-section.

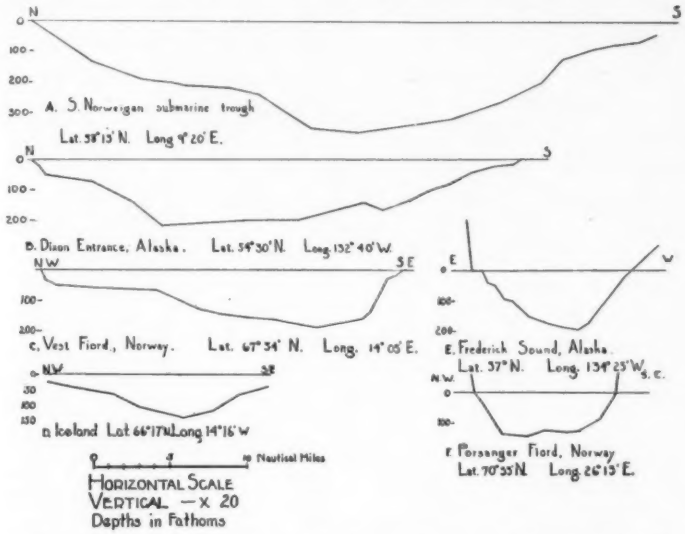

N
S
A. S. Norwegian submarine trough
Lat. 58°13' N. Long 4° 20' E.
B. Dixon Entrance, Alaska. Lat. 54°30' N. Long. 132° 40' W.
NW
SE
C. Vest Fiord, Norway. Lat. 67° 34' N. Long. 14° 05' E.
D. Iceland Lat. 66°17' N. Long. 14° 16' W
E. Frederick Sound, Alaska.
Lat. 57° N. Long. 134° 25' W.
F. Porsanger Fiord, Norway
Lat. 70° 35' N. Long. 26° 15' E.
10 Nautical Miles
HORIZONTAL SCALE
VERTICAL — X 20
Depths in Fathoms

FIG. 10.—Showing the similarity of the transverse sections of some of the broader outer portions of fiords to submarine glacial troughs. Figures *A* and *D* represent the troughs, *C*, *E*, and *F* represent fiords, and *B* represents an intermediate type.

Moraines.—The rims outside of the deeps in the troughs are in some cases of considerable extent longitudinally to the troughs, but in some cases they form narrow transverse bands (Fig. 11). It is hard to be sure that these bands are moraines, although that interpretation seems reasonable.

Helland found a moraine at Jaederen along the southwest coast of Norway,[1] which borders the submarine trough shown in Figure 9. The boulders in the moraine are said to have been derived from the vicinity of Oslo. They could not have come over the high interior so that they must have been carried to their present location by a

[1] Quoted by Nansen, *op. cit.*, p. 66.

glacier in the trough. A boring showed that the moraine had a minimum thickness of 400 feet.

Bottom character.—On most charts the general character of the bottom is indicated. In making use of this information several things must be borne in mind. For example, rock bottom should not be taken to mean that there is ledge rock outcropping, but that the

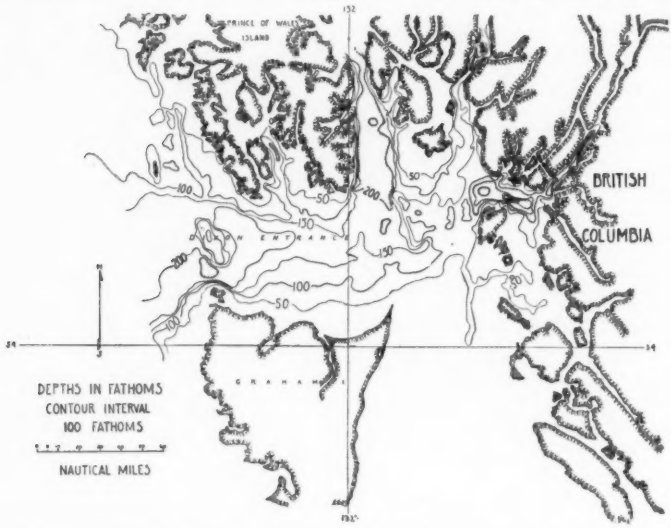


FIG. 11.—A trough along the coast of British Columbia. Note the shoal which nearly crosses the trough northwest of Graham Island and may represent a moraine. Source, U.S. Hydrographic Chart 2825 and Coast Survey Chart 8152.

sounding lead landed on either a ledge or a fragment of rock too large to be brought up by the tallow in the base of the lead. Also the specimens were not subjected to analysis, but were probably named on the basis of a brief examination. However, the information gives a rough idea of the covering of portions of the ocean floor. The sediment symbols were examined on the charts showing the troughs. Rock bottom, pebbles, and gravel were found to have an aggregate of 13 per cent. Considering the depth of these troughs this percentage of coarse material is rather significant. It is quite compatible with the idea that the troughs are glacial excavations.

OBJECTIONS TO THE GLACIAL HYPOTHESIS CONSIDERED

In talking to various geologists about the troughs several difficulties concerning the glacial interpretation were suggested to the writer. Each of these points will be considered in the following discussion.

Width.—Some of the troughs have been considered too wide to be the product of glaciation. Except for some of the doubtful cases in the Arctic, the St. Lawrence is the widest of the troughs, being about 70 miles across in some places. Is this width in excess of glacial features within the continents? Lake Superior and Lake Michigan have deep basins said to have been excavated by tongues of ice. Their widths are in each case greater than that of the St. Lawrence trough. Also some of the outer fiords of the coast of Norway are as wide as most of the troughs. Vest Fiord, for example, has a width of 35 miles.

Even floors.—It has been said that the floors of some of the troughs are too flat to be due to glaciation. It is observable that in some portions of the troughs there is a considerable degree of uniformity of depth. The great Norwegian trough has within it an area of 180 square miles with 54 soundings, all of them between 150 and 160 fathoms. These flats are not necessarily in the deepest portions of the troughs. They occur also on the side of deep depressions. The same relatively flat areas are found in fiords, glacial lake basins, and valleys of glacial excavation. The examination of fiord depths has shown uniform depths at a number of localities in the same fiord. Some of the Swiss lakes have been sounded with considerable detail and have been shown to have flat floors over a wide area.[1] U-shaped valleys are quite commonly flat at the base. The Yosemite is an example of the latter. The Rocky Mountain Trench shows evidence of having been shaped by a glacier. At one place its flat valley floor attains a width of 16 miles.

The cause of the flatness in the troughs, as in the fiords and glacial valleys in mountain ranges, is probably not so much glacial erosion as it is deposition by streams coming from the melting glaciers and subsequent marine deposition in the fiords and troughs. Since the ice sheets of the Wisconsin (Würm) stage of glaciation were not as

[1] F. A. Foral, *Le Leman*, p. 50.

extensive as those of some of the earlier stages, it seems likely that the troughs which were necessarily on the outer margins of glaciation were not occupied with ice during this last stage. Accordingly, deposition has had time to smooth out many of the irregularities. Where the flat zones occur as terraces above the deeper portions of the troughs, as in a few cases along the Norwegian coast, it may be assumed that the ice retreated by stagnation leaving large masses of ice to be surrounded by outwash sediments.[1]

Confining of ice erosion to the troughs.—While it is easily understood why glaciers should cut trough-like depressions out of preexistent river valleys, the cutting of troughs out on the continental shelves needs some explanation. Why did not the ice float away when it came out of the fiords or bays onto the shelf? The answer to this question is twofold. In the first place, the lowered sea level laid bare the continental shelves during the maximum stages of glaciation. Secondly, if the shelves were somewhat submerged the ice needed to be only about one-eighth thicker than the depth of water in order to rest on bottom.

Again it might be asked why the ice coming out of the fiord onto the flat continental shelves did not spread out to form piedmont glaciers. Nansen, who recognized the effect of ice on the shaping of some of these valleys along the Norwegian coast, answered the above difficulty by assuming that valleys had been cut across the shelf prior to glaciation and that the glacial tongues followed these preexistent depressions.[2] Since most coasts, whether they have been glaciated or not, have examples of submarine valleys this explanation has some probability. Possibly there were many more valleys in the continental shelf before the glacial period, some having been filled by sedimentation.

FAULT INTERPRETATIONS

In the case of several of the glacial troughs or of their landward continuations, the lateral slopes have been interpreted as faults or fault-line scarps. Since many cables cross these troughs it is important to examine the basis of this contention. In view of the straight-

[1] R. F. Flint recently described this condition from several regions.

[2] Nansen, *op. cit.*, pp. 57, 58.

ness of the trough sides and their comparatively steep slopes the fault interpretation appeared to be logical, provided glaciation were left out of the picture. However, if glaciers have cut these troughs, the question arises whether the ice did not produce the straight lateral escarpments as it has done in so many cases on the lands. Two cases will be considered, the "Fundian fault" and the "Cabot Strait graben."

The Fundian fault.—The escarpment on the northwest side of the Bay of Fundy was interpreted by Johnson[1] as a fault-line escarpment. He believed that the escarpment extended from near the head of the Bay of Fundy almost to the Isles of Shoals off Portsmouth. Studies by the writer[2] have brought out reasons for believing that the feature is much more restricted and consists of several escarpments which follow the Bay of Fundy only in part. This Bay has all the characteristics of the troughs referred to as intermediate between fiords and shelf-troughs (Fig. 12). It has steep sides, a broad base, deep depressions within the bay, and hanging valleys on the sides. That ice moved down the bay is indicated by striations found at its head and in a few places along the sides. Some detailed soundings by the writer showed indications of glacial erosion along the escarpments. Also a search for fault phenomena along the exposed upper portion of the escarpment at Great Wass Island had negative results. It was concluded that ice was probably the cause of the present form of the escarpments and that faulting need not be assumed.

The Cabot Strait graben.—The Grand Banks earthquake of November 18, 1929, focused some attention on the trough which comes out of the Gulf of St. Lawrence (Fig. 8). Cables were broken in a large zone which is roughly outside of the trough on the continental slopes and deep ocean bottom. This led several scientists to suggest that the feature was a graben.[3] The writer made some investiga-

[1] D. W. Johnson, *The New England Acadian Shoreline*, pp. 286–94.

[2] F. P. Shepard, *op. cit.*, pp. 659–74.

[3] J. W. Gregory, "The Earthquake South of Newfoundland and Submarine Valleys," *Nature*, Vol. CXXIV (1920), p. 945. Arthur Keith, "The Grand Banks Earthquake," *E. Sec. Seiss. Soc. of Am.*, supplement to proceedings of 1930 meeting; E. A. Hodgson, "The Grand Banks Earthquake," *ibid.*

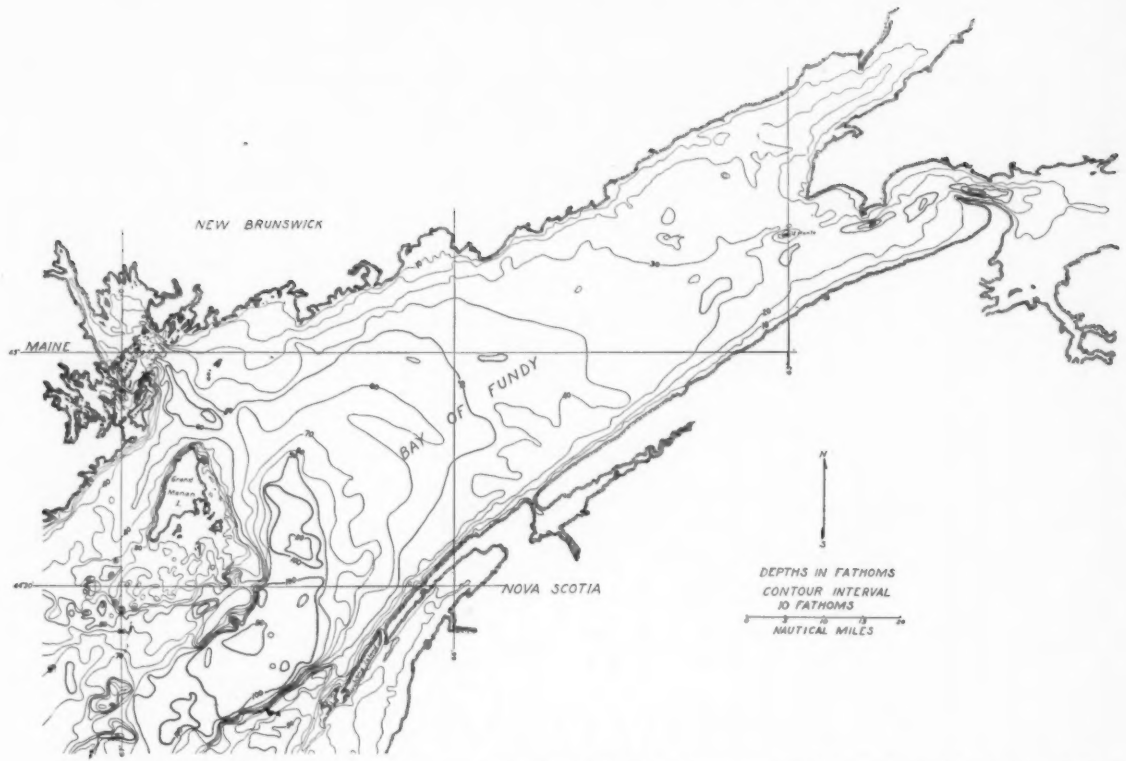


FIG. 12.—Illustrating the glacial-trough character of the Bay of Fundy. Source, various U.S. Hydrographic charts and Coast Survey charts.

tions of the trough particularly in the vicinity of Cabot Strait.[1] Glacial striae were found on both sides of the Strait which indicated that ice had passed through it. The structure of the rock showed no evidence of any faults parallel to the sides of the trough. Soundings made within the strait showed the scoop basin type of topography which has been described for other examples of the glacial troughs in the present paper. Furthermore the earthquakes and cable breaks were associated more with the very irregular topography of the continental slopes and deep ocean beyond than with the trough. The continental slopes off the Grand Banks have been subject to other earthquakes with breaking of cables in localities far removed from the St. Lawrence trough.[2] In fact, the continental slopes are so commonly the seat of earthquakes that the relationship to the trough could well be considered as a coincidence.

DEPTHS OF GLACIATED AND UNGLACIATED SHELVES

If the above interpretations are correct, the trough-shaped submarine valleys indicate that the great ice sheets sent tongues out beyond the present coastlines. That the shelves off glaciated coasts had more than tongues of ice crossing them might be suggested from the striking difference of the topography which they possess from that off unglaciated coasts. The depth of the shelves off glaciated coasts is easily twice that off unglaciated shelves. Along the glaciated coast from Cape Cod to the Straits of Belle Isle about 40 per cent of the shelf is deeper than 100 fathoms, whereas from Cape Cod down to Forida only about 0.5 per cent exceeds this depth. Along the west coast of North America the situation is similar. The glaciated zone from Cape Flattery in northeastern Washington to Cape Spencer, Alaska, has a shelf with about 30 per cent greater than 100 fathoms, while from Cape Flattery to San Francisco only about 3 per cent exceeds 100 fathoms. Turning to Europe we find the shelf off Norway with about 75 per cent greater than 100 fathoms and off Northern Europe about 55 per cent, while the shelf off the unglaciated west coast of France has only 1 per cent and the un-

[1] "The St. Lawrence (Cabot Strait) Trough," presented before Geological Society of America, 1930.

[2] John Milne, "Sub-Oceanic Changes," *Geog. Jour.*, X (1897), 261.

glaciated or slightly glaciated coast north of Siberia is bordered by a shelf which, according to rather fragmentary evidence, is one of the shallowest as well as one of the broadest in the world. The soundings off Antarctica show a shelf which is for the most part several hundred fathoms deep. These observations are too general to indicate that they are coincidences. The effect of glaciation has certainly produced deeper continental shelves. The deep depressions cannot be explained entirely as the work of glacial tongues. It seems highly probable that great ice sheets covered large parts of the shelves.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Mr. Thomas H. Shepard for the use of his yacht in gathering information concerning the east-coast troughs. For the purchase of hundreds of charts and the paying for a large amount of drafting work thanks are due to the Graduate School of the University of Illinois.

STRATIGRAPHY OF THE ORDOVICIAN HOUNSFIELD METABENTONITE

G MARSHALL KAY
Columbia University

ABSTRACT

The Hounsfield metabentonite, an altered volcanic ash of Ordovician Black River age, lying above the Leray and below the Watertown members of the Chaumont formation at its type section in New York, has been identified in sections in New York, Ontario, Wisconsin, Iowa, Minnesota, Missouri, Kentucky, and Tennessee. Stratigraphic sections are described from several regions, and the criteria supporting the identification of the beds with the type Hounsfield are summarized.

INTRODUCTION

The Hounsfield metabentonite has been defined as a bed of clay lying above the Leray limestone and below the Watertown limestone in the Chaumont formation of Ordovician, Upper Black River age east of Dexter, Jefferson County, New York.[1] The fact that the bed occurs in the type region of the Black River group enables one to give its age by definition rather than by correlation. The stratigraphic position of the metabentonite from New York to Minnesota has been found to conform to earlier and independently based correlations; this and other criteria establish the identity of the bed over a distance of nearly a thousand miles. The Hounsfield has been a key bed with reference to which precise stratigraphic relations of beds in local regions have been determined. The discovery of metabentonite in the several regions adds to the extensive area known to have been affected by dispersals of volcanic ash in early Mohawkian time.

The petrographic studies of the Mississippi Valley clay beds by Allen,[2] and the mineralogical studies of all the materials by P. F. Kerr, of Columbia University, show that the Hounsfield clays conform to the definition of metabentonite.[3]

[1] G. Marshall Kay, "Age of the Hounsfield Bentonite," *Science*, Vol. LXXII (1930), p. 365.

[2] Victor T. Allen, "Altered Tuffs in the Ordovician of Minnesota," *Jour. Geol.*, Vol. XXXVII (1929), p. 239; "Ordovician Bentonite in Missouri" (abstract), *Bull. Geol. Soc. Amer.*, Vol. XLII (1931) (in press).

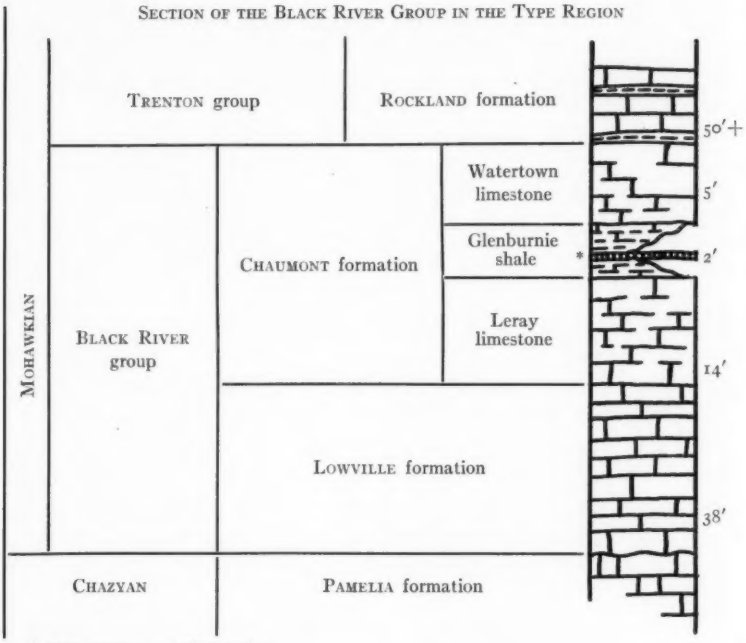
[3] C. P. Ross, "Altered Paleozoic Volcanic Materials and Their Recognition," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XII (1928), p. 164.

OCCURRENCE OF THE HOUNSFIELD METABENTONITE

Type section.—The Hounsfield metabentonite has its type locality in the region of the standard North American section of the Black River group of the Mohawkian series. Table I illustrates the relations of the several beds in that section.

TABLE I

SECTION OF THE BLACK RIVER GROUP IN THE TYPE REGION



* HOUNSFIELD metabentonite.

At the type section the Hounsfield is a thin bed of clay lying above the Leray Limestone and below the Watertown limestone of the Chaumont formation. The locality is a small quarry just north of the Dexter-Brownsville road at the foot of the west slope of the hill 2 miles east of Dexter, Jefferson County, New York. The quarry exhibits the section as shown in Table II.

The Rockland formation of the Trenton group is exposed along

the roadside to the east of the quarry; if the presence of *Triplecia cuspidata* (Hall) in abundance be evidence of the Rockland age of beds, the limestones are more than 53 feet thick.

Other sections in the vicinity.—The faunal and lithologic characters of the Leray and Watertown have not been ascertained to a degree

TABLE II

SECTION OF CHAUMONT FORMATION; TYPE LOCALITY OF THE HOUNSFIELD METABENTONITE

	Thickness of Bed	Distance from Top of Bed to Quarry Floor
BLACK RIVER GROUP:		
CHAUMONT formation:		
Watertown member:		
Heavy ledge of black, fine-textured, but distinctly crystalline, limestone, having discontinuous lenticular beds with undulating black shaly partings.....	4′ 6″	10′0″
Hounsfield metabentonite:		
Thin bed, variable in thickness, of grayish-white, homogeneous clay; very plastic and sticky when damp, with no tendency to part horizontally; chalky and brittle when dry, leaving flaky residue on exposure (see Fig. 1); reaching a thickness of.....	½″	6′3″
Leray member:		
Black, fine-textured limestone, quite like the Watertown, in thin beds with rather plane bedding planes; a species of *Mesotrypa* rare at the base.....	10″	6′2″
Beds of similar lithology in three ledges, the beds in the upper and lower being particularly lenticular; each of two upper ledges twenty-three inches thick, the lowest ledge eighteen inches thick; to base of quarry.....		5′4″

that permits their identification by means other than their stratigraphic positions. Were it not for the presence of the metabentonite in the Glenburnie shale between the Leray and Watertown members of the Chaumont north of Kingston, Ontario, the precise age of the Hounsfield might be difficult to prove; the metabentonite occurs as a thin clay seam 6 inches from the base of the Glenburnie at its type section.[1] The Glenburnie shale is exposed as far to the west as at Belleville, Ontario; the metabentonite has been identified at Napanee.

In most sections the movement of water through the soluble and

[1] G. Marshall Kay, "Stratigraphy of the Decorah Formation," *Jour. Geol.*, Vol. XXXIII (1929), p. 665.

jointed Watertown limestone would have removed any clay that might have been present at the base of the Watertown. The recognition of the Watertown limestone as a distinct unit at its type locality may be due in fact to the removal of the metabentonite seam, thus making the base of the ledge always obvious. In the large quarry at Pamelia, just southeast of Watertown, the Leray and

FIG. 1.—Hounsfield metabentonite above Leray limestone and below Watertown limestone in type section, east of Dexter, New York. The hand lens is sticking in the damp plastic clay.

Watertown limestones are separated by a conspicuous bedding plane, but any clay parting that may have been present has disappeared. It is only in such exposures as that at the type locality where the Trenton limestone has capped the exposure and protected the Chaumont beds that the metabentonite is preserved.

Some sections reveal neither the metabentonite nor a prominent bedding plane that might be ascribed to its removal. Thus in the continuous exposure of 19 feet of Chaumont limestones in the quarry just to the north of the village of Chaumont, there is no means of differentiating Leray and Watertown. Inasmuch as the Trenton

does not lie above the beds in the section, it is possible that the beds are entirely of the Leray. On the other hand, it is not improbable that there were parts of the sea bottom on which the volcanic ash was not deposited, and sections in such areas would presumably be like that at Chaumont. Ruedemann believed both Leray and Water-

TABLE III

SECTION IN QUARRY SOUTHEAST OF MIDDLEVILLE

	Thickness of Bed	Distance of Bed to Top of Lowville
TRENTON group:		
Formation presumably HULL:		
Grayish, crystalline limestone ledge, with brownish shale parting at the base; *Dalmanella rogata* (Sardeson), *Sowerbyella* sp., *Rafinesquina alternata* (Conrad), and other species abundant	11″	1′10″
Heavy bed of grayish, crystalline limestone of brecciated character, the included fragments being of fine-textured gray limestone	5″	11″
BLACK RIVER group:		
CHAUMONT formation:*		
Hounsfield metabentonite:		
Half-inch bed of light gray, homogeneous clay; plastic and sticky when damp, preserving this character in the exposure; enclosed in black, laminated, hard, brittle shale	1″	6″
Leray member:		
Bed of black, fine-textured limestone of somewhat hackly fracture; *Orthis tricenaria* Conrad and *Sowerbyella* sp. on upper surface	5″	
LOWVILLE formation:		
Very heavy beds of light-gray to white, fine-textured, sublithographic, plane-bedded limestone with small veins of calcite to floor of quarry	15′	

* The following beds may be younger than Chaumont.

town to be present in this quarry;[1] however, the Leray limestone may be a little thicker than is normal.

Exposure near Middleville.—Ninety miles southeast of Dexter a somewhat thicker bed of metabentonite is exposed in a quarry on the north side of the Middleville-Eatonville road, state highway 169, about a mile southeast of Middleville. The quarry exhibits the contact of the Black River and Trenton beds (see Table III and Fig. 2).

It is evident from the section that the metabentonite, though oc-

[1] Rudolf Ruedemann, "Geology of the Thousand Islands Region," *New York State Mus. Bull. 145* (1910), p. 90.

curring at a horizon that might be Hounsfield, is not defined by its position and restricted to a Hounsfield age particularly inasmuch as the bed beneath it is only questionably referred to the Leray.

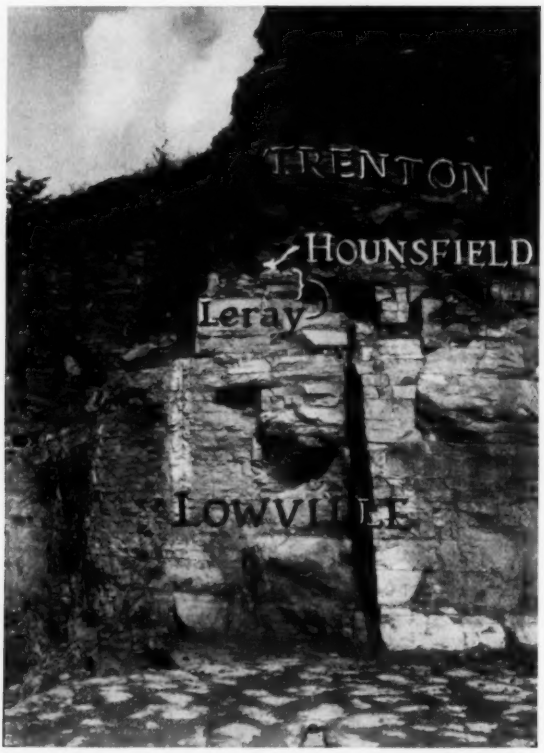


FIG. 2.—Section in quarry north of Road 169, a mile southeast of Middleville, Herkimer County, New York. The beds marked Leray and Hounsfield in the section may belong to the base of the Trenton.

The metabentonite and underlying limestone are younger than Lowville, and older than post-Rockland. The evidence in support of the post-Rockland age of the basal Trenton beds has been obtained along the Black River Valley to the northwest of Middleville. *Triplecia cuspidata* (Hall) is abundant 53 feet from the base of the

Trenton near Dexter, to 18 feet at Sugar River, and to 10 feet along the Black River northeast of Boonville; the species has not been observed at Middleville. It seems that as one proceeds southeastward along the Black River Valley from Watertown, successively younger beds of the Rockland lie on the Black River beds; that is, the beds overlap to the south. This may be interpreted as an evidence that the successive sections are not parallel to the old shore line, but those to the southeast are successively farther up on the land mass of Adirondackia. The Leray-Hull hiatus seems a local one occurring along the margin of the dome, for no such hiatus exists in the interior of the continent.

Further evidence with respect to the exact age of the metabentonite does not establish its Hounsfield identity. The lithology and the thickness of the bed are quite like those in the type section of the Hounsfield less than a hundred miles away; and if the thin bed beneath it be of the Leray, its stratigraphic position would seem proper. But an interpretation of its being of Hounsfield age introduces an assumption that a volcanic ash could have lain on the land through Watertown and Rockland time without being eroded; or if beneath the sea, without being covered by other sediments until post-Rockland time. In support of its Trenton age, the bed of underlying limestone is similar to those in the overlying Trenton beds. Such an assumption would require the coincidence of the contemporaneity of the beginning of Trenton deposition and the dispersal of the ash. No metabentonite has been observed in many sections of the basal Trenton either along the tributaries west of the Black River, or on those north of the Mohawk; but neither has metabentonite been observed at other horizons.

The metabentonite bed at Middleville is thus questionably the Hounsfield, and quite probably somewhat younger.

Sections in the Lake Simcoe Region, Ontario.—Metabentonite occurs in a number of exposures of the Coboconk limestone between Lake Simcoe and Georgian Bay, in Simcoe County, Ontario. The best of the exposures are in the large quarries at Uhthoff and Medonte on the Canadian Pacific Railway between Orillia and Coldwater. The section in the quarry just southwest of the railroad sta-

tion at Medonte, 12 miles northwest of Orillia in Lot 20, Concession XII, Medonte Township, is shown in Table IV.

In the quarry just southwest of Uhthoff station on the Canadian Pacific, in Lot 10, Concession IV, Township Orillia North, the metabentonite occurs 12 feet from the floor of the quarry in its west face, beneath 15 feet of upper Coboconk limestone; the section is quite like that at Medonte. The metabentonite is missing along the

TABLE IV

SECTION IN QUARRY AT MEDONTE, ONTARIO

	Thickness of Bed	Distance from Top to Floor of Quarry
BLACK RIVER GROUP:		
COBOCONK formation:		
Limestone beds of variable character, some crystalline, others sublithographic	12′0″	31′0″
Hounsfield metabentonite: Thin bed of blue-gray and tan, homogeneous clay; plastic when wet, breaking with somewhat micaceous fracture when dry	½″	19′0″
Very heavy bed of fine textured, very light gray limestone, sublithographic	2′0″	
Interbedded fine-textured, very light gray limestones and blue-gray, laminated, papery, tough shales, the latter containing leperditiid ostracods	3′8″	17′0″
Heavy beds of fine-textured sublithographic limestone overlying beds of little more evidently crystalline character to the floor of the quarry		13′4″

south face of the quarry. Maddox[1] has reported the presence of "bentonite" in a well cutting from the Robert Cherry No. 1 well, 2½ miles southeast of Collingwood, Ontario; this is about 30 miles west of the localities described. The metabentonite, which "probably occurs in the upper part of the Black River limestone," is presumably the same as that exposed in the Coboconk at the outcrop; the presence of 35 feet of limestone below the metabentonite and above basal sandstones would seem to support that identification.

It is evident that if the metabentonite is of Hounsfield identity, the Coboconk limestone is not "to be correlated with the Leray limestone of New York,"[2] but the upper part is younger than

[1] D. C. Maddox, "Bentonite in the Ordovician near Collingwood, Ontario," *Science*, Vol. LXXII (1930), p. 630.

[2] W. A. Johnston, "Simcoe District, Ontario," *Geol. Surv., Can. Summ. Rept. for 1911* (1912), p 189.

Leray and of Watertown age. The fact that the Watertown fauna cannot be distinguished from that of the Leray, and that the Glenburnie fauna seemed absent in the Lake Simcoe region led the writer to correlate the upper part of the Coboconk with the Watertown.[1] The abundance of specimens of *Columnaria halli* Nicholson, *Stromatocerium rugosum* Hall, *Actinoceras tenuifilum* (Hall), and *Streptelasma profundum* (Conrad) in the quarries north of Longford, in the east part of Lot 24, East Range, Rama Township, Ontario County, a few miles east of Medonte, is suggestive of the faunule in the Watertown limestone at Glenburnie; in parts of the exposure the first two species form a considerable part of the mass of the limestone.

Inasmuch as the metabentonite occurs in each exposure of the Coboconk, and only one metabentonite is present, the bed seems identical with the type Hounsfield metabentonite.

OCCURRENCE OF METABENTONITE IN THE MISSISSIPPI VALLEY

The section in which the Hounsfield metabentonite occurs in Wisconsin, Iowa, and Minnesota is as shown in Table V. The stratigraphy of the beds has been discussed elsewhere.[2]

Section near Platteville, Wisconsin.—The metabentonite has been found in the type section of the Platteville formation about 2 feet from the base of the Spechts Ferry member. Table VI is the section in the ravine in the center of the northwest quarter of Sec. 20, T. 3 N., R. 1 W. (Platteville Township, Grant County, Wisconsin).

Section at Potosi, Wisconsin.—An exposure in the north fork of the ravine extending westward from Potosi Creek just north of Potosi station, in the southwest quarter of Sec. 4, T. 2 N., R. 3 W. (Potosi Township, Grant County) reveals the metabentonite at about the same distance from the base of the typical Spechts Ferry shale as it is above the "glass rock" at Platteville. The Potosi section is identical with that of the type section of the Spechts Ferry member across the river in Iowa;[3] the section is described in Table VII.

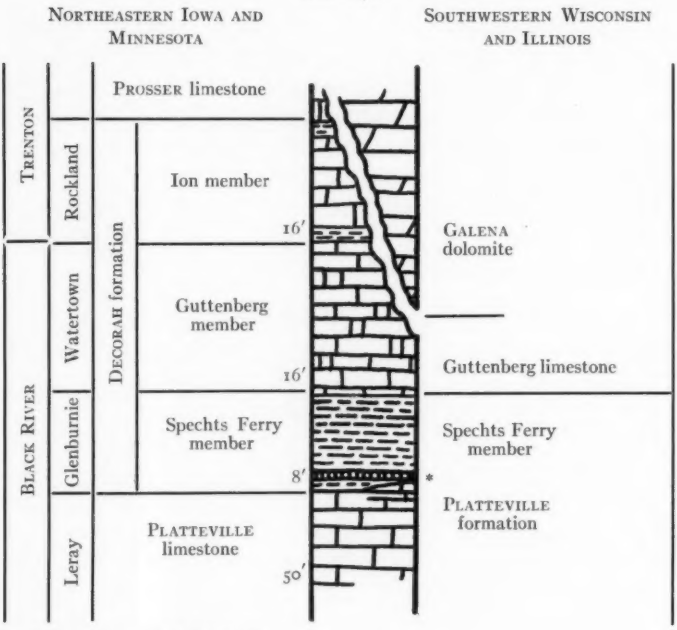
[1] G. Marshall Kay, *op. cit.*, pp. 666–67.

[2] *Ibid.*, p. 643; and "Formations Subjacent to the Black River–Trenton Line" (abstract), *Bull. Geol. Soc. Amer.* Vol. XLI (1920), p. 201.

[3] G. Marshall Kay, "Stratigraphy of the Decorah Formation," *Jour. Geol.*, Vol. XXXVII (1929), p. 646.

This and similar sections support the conclusion that the beds between the Hounsfield metabentonite and the Platteville limestone proper (that is, the beds of the Platteville below the type Spechts Ferry) are wholly equivalent to the beds above the "glass rock" and

TABLE V



* Hounsfield metabentonite.

below the metabentonite at Platteville; it was on the basis of these stratigraphic relations that the "glass rock" was stated to be definitely older than the base of the Spechts Ferry.[1]

Other exposures in the Upper Mississippi Valley.—The metabentonite has been found in every section of the basal Spechts Ferry that has been carefully examined; it occurs consistently about a foot from the base of the member. Thus at Guttenberg, Clayton County,

[1] G. Marshall Kay, "Formations Subjacent to the Black River–Trenton Line," (Abstract), *Bull. Geol. Soc. Amer.*, XLI (1930), p. 201.

Iowa, it is well exposed along the roadside of federal highway 55 just northwest of the city; see Figure 3. The base of the Spechts Ferry has the thin bed of "intraformational conglomerate," yellowish-green, flattened shale pebbles in a much darker shale matrix,

TABLE VI

SECTION TWO MILES WEST OF PLATTEVILLE, WISCONSIN

	Thickness of Bed	Distance from Top of Bed to Base of Member
GALENA formation:		
Guttenberg member (Decorah in age):		
Two- and 3-inch beds of brownish, fine-textured, fossiliferous limestone, with intercalated beds of "oil-rock" shale, brownish, brittle, and tough		
PLATTEVILLE formation:		
Spechts Ferry member (Decorah in age):		
Bluish-gray, fine-textured, hard, massive limestone with black pyritic nodules and minute gastropods; forming brink of falls in stream	4″	4′7″
Blue-green, laminated, argillaceous shale, including beds of hard, pyrite-containing, fossiliferous blue shale	1′ 9″	4′3″
Several beds of structurally shaly limestone, several very crystalline and containing an abundance of specimens of *Pionodema subaequata* (Conrad), *Orthis tricenaria* Conrad, and bryozoa, particularly *Homotrypa minnesotensis* Ulrich	10″	2′6″
Hounsfield metabentonite: two-inch bed of homogeneous, plastic clay, the upper part yellowish-tan, the lower light blue-gray in color	2″	1′8″
Beds of limestone, some purplish, crystalline and highly fossiliferous, others fine-textured and gray, with intercalated greenish shale bed containing *Poterioceras* sp. and many specimens of *Homotrypa minnesotensis* Ulrich	1′ 6″	
Base of Spechts Ferry member:		
The "glass rock"—dark-gray, fine-textured, very hard, brittle and tough, plane-bedded, non-laminated limestone, breaking conchoidally, splintering, resonant when struck; containing a few extremely well-preserved fossils in a bed a foot from the base	3′ 4″	

that is often found at the base of the member. The metabentonite is intercalated within the greenish, brittle argillaceous shales above it, there being a yellowish sandy bed adjacent to the clay.

And in a section excavated along the bank of the road between Dunning Spring and federal highway 55 just north of the Upper Iowa River in the northwest quarter of Sec. 16, T. 98 N., R. 8 W. (Decorah Township, Winneshiek County, Iowa) in the city of

Decorah, a bed of white, homogeneous clay, quite plastic when wet, was exposed 21 inches from the top of the Platteville in similar blue-green shales. The metabentonite has been reported and described

TABLE VII

SECTION OF SPECHTS FERRY MEMBER OF THE PLATTEVILLE FORMATION AT POTOSI, WISCONSIN

	Thickness of Bed	Distance from Top of Bed to Base of Member
GALENA formation:		
Guttenberg member (Decorah in age):		
Two- and 3-inch beds of brownish, fine-textured, fossiliferous limestone with a few intercalated beds of "oil rock" shale; and a four-inch bed of green shale seven inches from the base		
PLATTEVILLE formation:		
Spechts Ferry member (Decorah in age):		
Grayish, homogeneous, fine-textured limestone containing minute gastropods and phosphatic nodules.....	4″	7′ 7″
Greenish-blue, laminated, argillaceous brittle shales, with interbedded dark blue, thinly laminated, hard, highly fossiliferous, pyritic shales; and gray fine-textured, hard, homogeneous, non-laminated beds of limestone two to four inches thick, 2′4″, 3′, and 4′10″ from the base.....	6′5″	7′ 3″
Hounsfield metabentonite—very thin bed of plastic, grayish clay, intercalated within beds of fine-textured, rather soft limestone.....	6″	10″
Bluish, laminated, brittle shale, containing many specimens of *Pionodema subaequata* (Conrad).....	4″	
Base of Spechts Ferry member:		
Beds of gray, fine-textured, hard, brittle limestone—these beds are not of the same character as those of the "glass-rock" at Platteville		

in some detail from its occurrence a foot and a half from the base of the Decorah formation at Minneapolis, Minnesota.[1]

The base of the Spechts Ferry has been correlated with the base of the Glenburnie shale of Ontario;[2] the fact that the metabentonite occurs at precisely the anticipated correlative horizon would confirm the identity of the bed with the Hounsfield.

Occurrence in Missouri.—The metabentonite bed at the base of

[1] F. W. Sardeson, "Volcanic Ash in the Ordovicic Rocks of Minnesota," *Pan-Amer. Geol.*, Vol. XLII (1924), p. 45; Victor T. Allen, "Altered Tuffs in the Ordovician of Minnesota," *Jour. Geol.*, Vol. XXXVII (1929), p. 239.

[2] G. Marshall Kay, "Stratigraphy of the Decorah Formation," *Jour. Geol.*, Vol. XXXVII (1929), p. 668; "Correlatives of the Mohawkian Sediments in Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XIII (1929), p. 1213.

the "Decorah" formation in Missouri has been reported by Allen.[1] Seven to 10 inches of metabentonite are present at the base of the green shales that overlie the Plattin limestone along federal highway

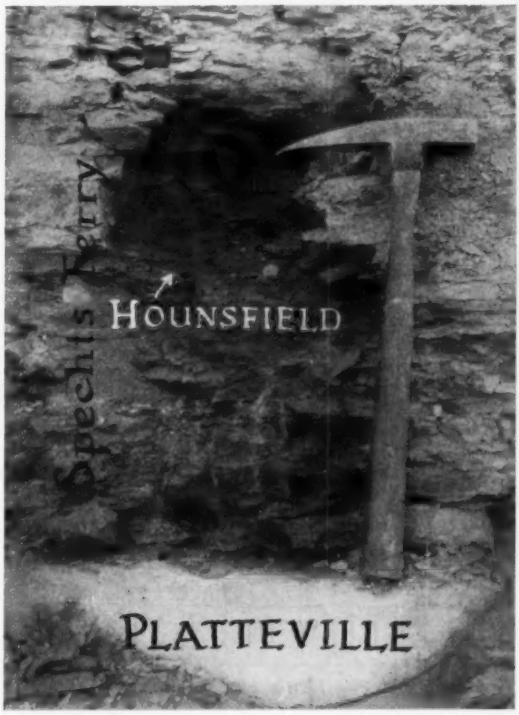


FIG. 3.—Hounsfield metabentonite 10 inches from the base of the Specht's Ferry member of the Decorah formation along federal highway 55, northwest of Guttenberg, Clayton County, Iowa.

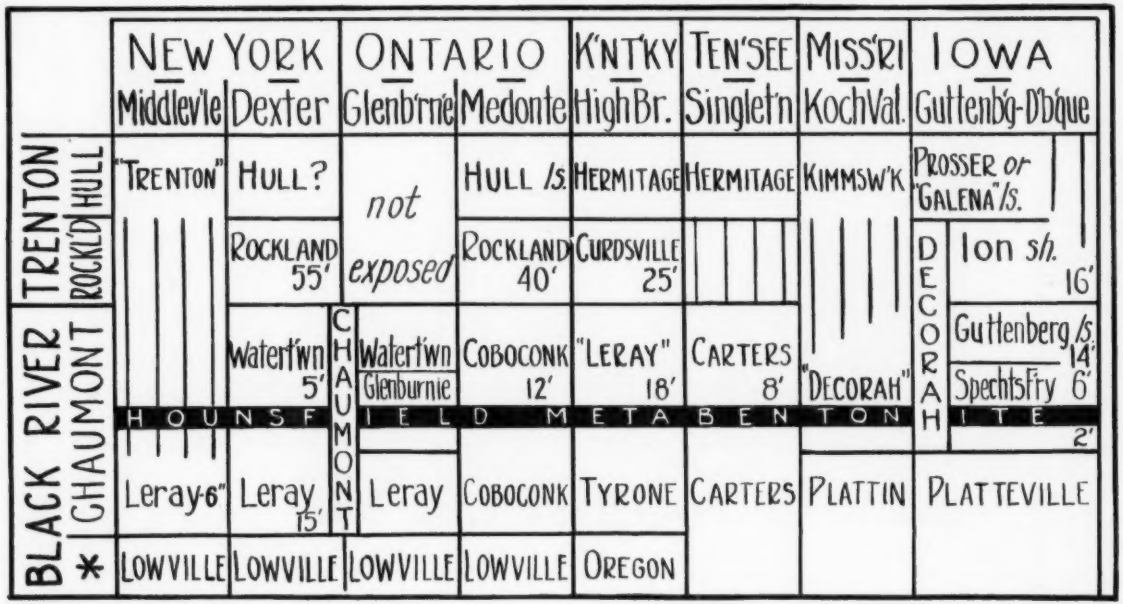
61 near Koch Valley, 26 miles south of St. Louis. The Missouri "Decorah" beds have been correlated by Weller[2] and others with the Decorah formation of Iowa. It is rather the correlative of the Specht's Ferry and perhaps in its upper part the Guttenberg mem-

[1] Victor T. Allen, "Ordovician Bentonite in Missouri" (Abstract), *Bull. Geol. Soc. Amer.*, Vol. XLII (1931) (in press).

[2] Stuart Weller, "Geology of Ste Genevieve County, Missouri," *Mo. Bur. Geol. Mines*, Vol. XXII (2d ser., 1928), p. 111.

TABLE VIII

CORRELATION TABLE OF THE SECTIONS IN THE SEVERAL REGIONS WITHIN WHICH HOUNSFIELD METABENTONITE OCCURS
THE EXTENSIVE DISTRIBUTION OF BEDS OF WATERTOWN AGE IS EVIDENT



* LOWVILLE

ber of the Decorah formation, for the fauna reveals no Upper Decorah Ion affinities.

The occurrence of the metabentonite at the base of the Spechts Ferry correlative is again at an anticipated position in the section; the greater thickness has been attributed with seeming propriety to the region's being relatively closer to the source of the ash than is Iowa. The identity of the metabentonite in the Missouri "Decorah" to that in the base of the Spechts Ferry member of the Decorah formation in Iowa, Wisconsin, and Minnesota can hardly be questioned.

Metabentonite in southern states.—"Bentonite" has been reported as occurring in Upper Black River formations in Kentucky and Tennessee[1] and in the basal Trenton near Birmingham, Alabama;[2] though the last has been correlated with the Kentucky and Tennessee beds,[3] the fauna of the including beds seems the same as that of the younger Curdsville formation of Kentucky. In Kentucky, the metabentonite bed is 5 feet thick, and occurs about 18 feet from the top of the Tyrone limestone; the beds at the top of the Tyrone have been called the "Leray" limestone, but if the metabentonite bed is the Hounsfield, as it seems to be, the upper Tyrone is younger than Leray and of Watertown age. In the Tennessee section, the metabentonite likewise occurs a few feet from the top of a limestone, the Carters, of Black River age; the section is quite similar to that in Kentucky.

The sections in Kentucky and Tennessee are most like those in the Lake Simcoe region, Ontario. In each case there are several feet of Upper Black River limestones above the metabentonite. The beds in Kentucky have been called the "Leray limestone," just as was the Coboconk prior to its being given a distinctive name. The greater thickness of the Southern metabentonites is quite consistent with the opinion that the volcanic vent that furnished the ash in Ordovician time was located in Southeastern United States; it would be anomalous if the Southern beds were not thicker than those in Ontario.

[1] W. A. Nelson, "Volcanic Ash Beds in the Ordovician of Tennessee, Kentucky, and Alabama," *Bull. Geol. Soc. Amer.*, Vol. XXXIII (1922), p. 605.

[2] Charles Butts, "Geology of Alabama," *Ala. Geol. Surv., Spec. Pub. 14* (1926), p. 131.

[3] W. A. Nelson, *op. cit.*, p. 607.

CRITERIA SUBSTANTIATING HOUNSFIELD IDENTITY OF METABENTONITES

The identity of the Hounsfield metabentonite in the several regions has been established by means of a number of criteria. (1) The lithology of the bed in the different sections is quite the same. Lithology alone cannot prove identity; there are several similar metabentonites in Pennsylvania of different Ordovician ages.[1] But similarity does substantiate other evidences; and detailed mineralogical studies may reveal information that will permit the more practical use of the lithologic characters of metabentonites. (2) The fact that in each case the metabentonite occurs in a horizon that had been correlated with the post-Leray pre-Watertown horizon of the Hounsfield in the type section independent of the discovery of metabentonite is practically proof of the identity of the beds inasmuch as (3) a single metabentonite has been found at such horizon in each region in which rocks of such age have been critically studied, but in no region have two such beds been found. This would seem to show that only a single ash dispersal affected the regions during middle Chaumont time. (4) The thicknesses of the volcanic deposits are consistent with the view that the volcanic vent which dispersed the ash was in Southeastern United States; for the thicknesses in areas adjacent to that region are greater than at more distant localities. In single regions the thicknesses of the metabentonite bed are quite uniform.

SUMMARY

The Hounsfield metabentonite is a bed of altered volcanic ash of Ordovician, late Black River age, occurring above the Leray and below the Watertown members of the Chaumont formation in section. The bed has been recognized in a number of regions in Eastern North America; and the area affected by the ash dispersal is a very large one.

Sections have been listed in the several regions in which the metabentonite occurs, and the criteria that warrant the identification of the beds in these regions with the type Hounsfield have been stated.

[1] C. A. Bonine and A. P. Honess, "Bentonite in Pennsylvania," *Proc. Pa. Acad. Sci.*, Vol. III (1929), p. 23; *Pa. State Coll., Min. Indus.-Exp. Sta., Bull. 5* (1929), p. 6.

ORIGIN OF THE PEBBLE BAND ON IOWAN TILL[1]

GEORGE F. KAY
University of Iowa

ABSTRACT

According to one view, the pebble band on the Iowan till is the result of wind action in a marginal area during the retreat of the Iowan ice. An alternative interpretation is that the pebble band is the result chiefly of the erosion of Iowan till by running water, considerable time having been involved in its formation.

Within the area of Iowan drift in northeastern Iowa thin Peorian loess overlies in many places a distinct pebble band at the surface of the Iowan till. Where the pebble band is absent, the loess lies directly on the till. Where no loess is present on the till, the till in upland sections is leached to a depth of approximately 5 feet. Where loess is on the pebble band or on till and is of sufficient thickness to be unleached in its lower part, the underlying Iowan till is unleached to its surface. Where the loess is thin and leached, the upper part of the till is leached also, whether the pebble band is or is not present, the combined leaching of the loess and till being about the same in depth as where no loess overlies the till.

Thick Peorian loess which is apparently genetically related to the Iowan till is uniformly present beyond the borders of the Iowan drift where presumably good anchorage was afforded by the vegetation of the extra-marginal Kansan drift areas. This loess thins with distance from the Iowan; and, furthermore, the constituent parts of the loess are largest at the border of the Iowan and become smaller and smaller as distance increases from the border.

One of the best exposures within the whole Iowan area showing the line of pebbles with Iowan till below and loess above was observed in a road-cut in the middle of the line between Sections 1 and 2, Fremont township, Cedar County (Fig. 1). This cut is in an area of gentle topography. The section is as follows:

[1] This article presents what is regarded as an unsolved problem. The companion article by Professor Hobbs, immediately following, aids in its solution.—THE EDITOR.

1. Loess (Peorian), oxidized to brownish color, leached..... 4 feet
2. Pebble band, a thin row of pebbles
3. Till (Iowan), oxidized, grayish yellow to yellow color, no ferretto, sandy, contains sand pockets, jointed, upper 1 foot 3 inches leached, lower part unleached..... 5 feet

Here some of the fragments of rock in the pebble band show wind polish (Fig. 2). But in many places the pebbles of the pebble bands

FIG. 1.—Road-cut between Sections 1 and 2, Fremont Township, Cedar County, showing thin pebble band with Iowan till below and Peorian loess above.

lack evidence of wind action. Nor do the pebbles show surface effects due to water action; they are similar to the pebbles which are common in glacial till.

Two interpretations of the origin of the pebble band on Iowan till have been given. Alden and Leighton[1] and the writer[2] have ex-

[1] W. C. Alden, and Morris M. Leighton, "The Iowan Drift, a Review of the Evidences of the Iowan Stage of Glaciation," *Iowa Geol. Surv.*, Vol. XXVI (1917), pp. 83, 156.

[2] G. F. Kay, "The Relative Ages of the Iowan and Illinoian Drift Sheets," *Amer. Jour. of Sci.*, Vol. XVI, (1928), pp. 506–8.

pressed the judgment that the pebble band is probably the residual coarse material left from the slight wind erosion and rain wash which occurred in places before the till was protected by the loess. The evidence suggests strongly that the pebble band was formed and the overlying loess was deposited in a comparatively short time after the deposition of the Iowan till. In fact, the area within which

FIG. 2.—One of the rock fragments of pebble band underlain by Iowan till and overlain by Peorian loess.

the pebble band was developed was probably a marginal area free from vegetation in front of the retreating Iowan ice sheet. Winds blowing outward from the diminishing glacier picked up the fine material from the ground moraine and outwash areas from which the ice sheet had withdrawn, leaving a pebble band, which soon afterward was covered by loess which was being deposited and redeposited within the area of wind action.

The second interpretation of the origin of the pebble band has been advanced by Leverett.[1] He considers the pebble band to have been the result chiefly of the erosion of several feet of the Iowan till

[1] Frank Leverett, "The Pleistocene Glacial Stages: Were There More than Four?" *Proc. Amer. Phil. Soc.*, Vol. LXV (1926), No. 2, p. 111.

by running water, and that considerable time was involved in its formation. He favors the view that the till on which the pebble band was formed was the result of an ice sheet from the Keewatin field and equivalent in age to a late phase of the Illinoian drift. He is of the opinion that the time between the deposition of the till within the Iowan area and the deposition of the overlying Peorian loess was comparable to the time between the deposition of the Illinoian drift and the deposition of the Peorian loess overlying the Illinoian drift. He would make the Iowan drift the product of a late phase of the Illinoian age of glaciation and would apply the name Sangamon to the interval between the time of deposition of the Iowan drift and that of the overlying Peorian loess as well as to the time of deposition of the Illinoian drift and that of the Peorian loess which overlies it. On this interpretation the pebble band was formed not by wind action but chiefly by slope wash during the long Sangamon interval.

LOESS, PEBBLE BANDS, AND BOULDERS FROM GLACIAL OUTWASH OF THE GREENLAND CONTINENTAL GLACIER

WILLIAM H. HOBBS
University of Michigan

ABSTRACT

This paper discusses the action of the glacial anticyclone of Greenland upon the outwash deposit at its front, and the manner of deposition of loess, pebble layers, and stranded boulders etched by drifting sand which is now collected in dunes. Of much significance is the fact that the braided streams on the outwash plain flow only for a few months of the year.

The station of the University of Michigan expeditions at Mount Evans, Greenland, supplied perhaps the best opportunity yet made available to study existing climatic and resulting geological conditions near the border of an ice sheet of the kind that lay over Northern North America. This is true because within the antarctic region comparatively small land areas lie exposed, and, further, because all expedition bases there, save only that of Sir Douglas Mawson in Adelie Land (1911–14), were located far from the inland ice border. So far as Greenland is concerned, most former expedition bases have been placed close to the sea, and in some cases far from the inland ice border where domination of the wind by the glacial anticyclone is less complete.

The Mount Evans base was purposely selected where the land area marginal to the inland ice has its greatest width. For a distance of about 175 miles to the north and south of the station, the ice margin has an enclosing strip of land of an average width of nearly 100 miles. At the station itself, which is about 25 miles distant from the present ice border, throughout the two-year period during which the station was in operation all strong surface winds blew outward off the inland ice. These included in each year many violent storms, some of which attained hurricane velocities; and, though more common in winter time, in at least one instance a storm of hurricane force arrived in midsummer. That the force of these surface winds falls off somewhat rapidly after passing the ice margin was clearly

indicated in several ways, and especially by their effect upon the vegetation. The willows and birches, which are generally low shrubs from one to two feet in height, in some exposed places near the ice margin were found growing flat on the ground with their branches spread out to leeward like the sticks of a Spanish fan.

Wherever a tongue of ice pushes out from the parent mass of the inland ice—and in Greenland this is generally at the head of a fjord or of a fjordlike valley—a valley flat of outwash material has been built up, and through this during the summer season the thaw water from the ice flows in braided streams (Fig. 1).

FIG. 1.—A valley flat of outwash at the head of a fjord valley below an outlet glacier from the inland ice of Greenland.

At the front of the glacier the ice cliff is, during the summer months, in a weakened state due to thawing temperatures. At frequent intervals blocks of ice fall from the cliff, and fragments which may include rock boulders are in part carried out in the braided streams which course over the outwash plain (Fig. 2). These streams are large or small according as the weather is relatively warm or cool, but with a lag of the stream behind the weather which is measured in hours only. After a warm spell which extends over several days, the outwash flat may be found in large part submerged; but after a corresponding cool period, the flowing water is reduced to a few easily fordable streams. In the early fall when thawing of the ice comes to an end, the flow of streams ceases entirely, and the plain is everywhere dried out. It is this seasonal life of the streams, and their extinction during the season when the storms off the ice

have greater frequency and increased violence, which plays so important a rôle in the behavior of the materials composing the outwash plain.

Dried out at the surface, the finer materials of the outwash become the easy prey of the wind and cause sand storms which are comparable to those of deserts. Even in the summertime, sand storms which are extremely difficult to face are not unusual. In

FIG. 2.—Boulders scattered by floating ice over an outwash plain now uplifted and forming a terrace near the head of the Söndre Strömfjord. In the foreground a boulder strongly etched by the sand blast.

winter these storms are so much the more violent, and the sand is carried far and laid down over snow to produce a "sandpaper" surface particularly serious for sledging parties.

From the mixture of rock-flour with coarser materials which compose the outwash, the wind carries away the dust and finer sand, to leave behind a surface layer which near the ice front is a pebble band and further away a gritty sand—in either case a layer composed of the coarsest material which had been present in the outwash. Earlier flats of outwash materials have in the Greenland fjords been subsequently uplifted, and after dissection by the

streams they now stand out as terraces of variable width lining the valley walls.

During storms the air is so filled with dust that traveling is difficult when directed toward the ice front. For days during the characteristic foehn storms the air about the Mount Evans Observatory, distant 25 miles from the ice front and nearly 1,300 feet up from the fjord, is so filled with dust that visibility is greatly reduced. This dust is caught in the tundra-covered district so that some miles distant from the ice border walking in the tundra raises a cloud of

FIG. 3.—Small sand dunes formed about vegetation along the sides of the valley flats of the Söndre Strömfjord, Southwest Greenland.

dust and the clothing becomes covered with it. That the surface of the ground is in some places materially raised as a result of this loess deposit is indicated by caribou antlers, which are sometimes buried in the tundra to as much as a third of their height.

The sand removed from the valley flats is collected in great dunes within sheltered places along the sides of the valley, and in smaller accumulations it is collected about vegetation covering much larger areas along the sides of the flats (Fig. 3). This sand, while in transit, has attacked the boulders so that examples of "stone lattice" are found in great numbers (Fig. 2).

All the characteristic effects of the wind within the better-known desert areas of lower latitudes are here found reproduced on or

about the outwash plains of the continental glacier of Greenland—there are the Armored floor (pebble bed), the loess deposits within a zone marginal to the glacier, scattered boulders profoundly etched by sand-blast erosion—and all explained by the wind of the glacial anticyclone generated by the glacier itself and operating upon its own outwash deposit.

There is, of course, one notable difference between the area about the present continental glacier of Greenland and that about the continental glaciers of the Pleistocene in North America and Europe. The Greenland ice sheet is surrounded by a rugged plateau deeply dissected and representing differences of level of several thousand feet; whereas the continental glaciers of North America lay over much flatter country. Within the middle Mississippi Valley the zone of outwash, instead of being restricted to the heads of fjord valleys, as it now is in Greenland, must have formed an almost continuous zone marginal to the ice sheet. Under such conditions one may picture a zone of loess marginal to the ice, deposited in places upon till, and exhibiting thin pebble beds and scattered boulders which are etched by the sand blast as these have been found in Iowa particularly. Deposits of till would also to some extent supply materials for wind transport. In Southeast Greenland, however, there is found but little till to be affected.

WARPING OF APPALACHIAN PENEPLAINS

KARL VER STEEG
College of Wooster

ABSTRACT

Because the Harrisburg peneplain has a pronounced slope toward the southeast, it has been believed that widespread warping of that surface took place in the uplifting of the Appalachians. There is reason to doubt this supposed warping, for evidence of it appears to be lacking in eastern Pennsylvania where the surface has its best development.

PENEPLAINS OF THE NORTHERN APPALACHIANS

Davis in his papers, "The Geographic Development of Northern New Jersey"[1] and "The Rivers and Valleys of Pennsylvania,"[2] recognized the remnants of two peneplains; one represented by the even crest-lines of the ridges which he considered to be of Jura-Cretaceous age and another developed on the soft rocks of the Kittatinny Valley and on the Newark rocks which form a broad, lowland belt across the two states, and which he believed to be of late Tertiary age. Campbell in his paper[3] on the "Geographic Development of Northern Pennsylvania and New York" recognized a peneplain which he called the Harrisburg, lying between those described by Davis, which is less extensive than the Schooley (Jura-Cretaceous) and much better developed than the late Tertiary or Somerville plain, and which presumably was produced in the early stages of the Tertiary period. The Harrisburg peneplain is best developed in the Great Valley on the shales of the Hudson River formation, which offer moderate resistance to erosive agencies and in consequence stand above the level of the limestone portion of the valley as a hilly upland.

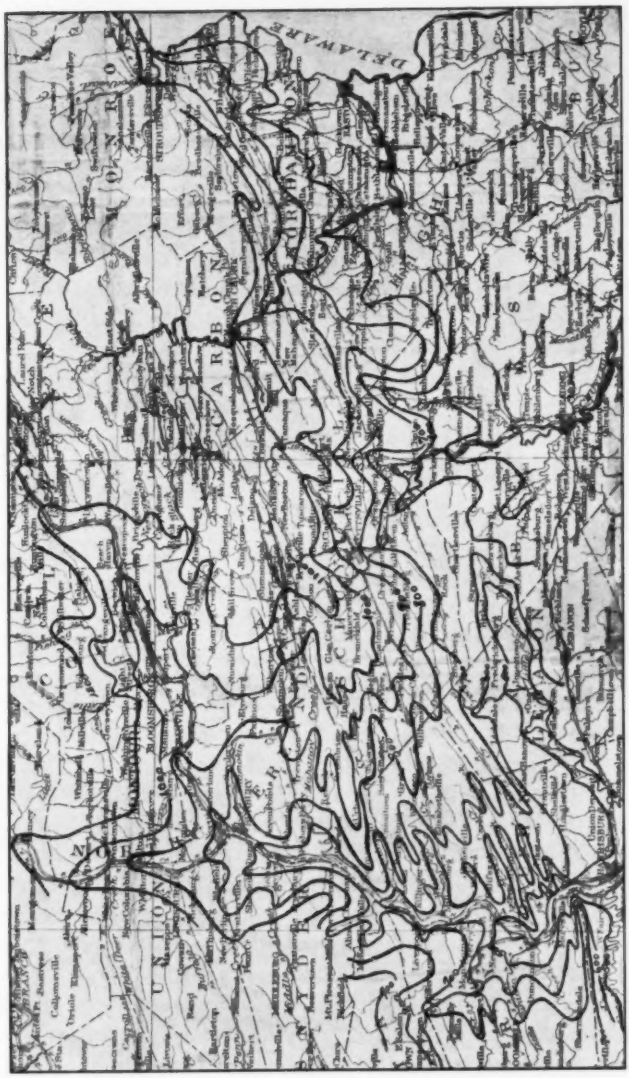
THE FORM AND CHARACTER OF THE HARRISBURG PENEPLAIN

The writer constructed a contour map of a portion of the Harrisburg surface (Fig. 1). The restored peneplain, however, does not show the ridges and monadnocks, the purpose being to bring out its

[1] W. M. Davis, and J. W. Wood, "The Geographic Development of Northern New Jersey," *Proc. Bos. Soc. of Nat'l Hist.*, Vol. XXIV (1888–90).

[2] W. M. Davis, "The Rivers and Valleys of Pennsylvania," *Nat'l Geog. Soc. Mon.*, Vol. I., No. 10, pp. 305–36.

[3] M. R. Campbell, *Bull. Geol. Soc. Amer.*, Vol. XIV (1903), pp. 277–96.


DELAWARE
CHESTER
MONTGOMERY
BUCKS
LEHIGH
NORTHAMPTON
BERKS
LANCASTER
YORK
ADAMS
Philadelphia
Reading
Lancaster
Harrisburg
Gettysburg
Allentown
Bethlehem
Easton
Norristown
Coatesville
Doylestown
Quakertown
Pottstown
Kutztown
Hanover
Chambersburg
Carlisle
Mechanicsburg
Lebanon
Ephrata
Lititz
Manheim
Columbia
Elizabethtown
Middletown
Hershey
Pottsville
Tamaqua
Shamokin
Mahanoy City
Ashland
Frackville
Shenandoah
Mount Carmel
Centralia
Minersville
Schuylkill Haven
Orwigsburg
Auburn
Tremont
Hamburg
Boyertown
Douglassville
Birdsboro
Kutztown
Fleetwood
Womelsdorf
Robesonia
Wernersville
Sinking Spring
Shillington
Mohnton
Wyomissing
Temple
Mount Penn
Lyons
Myerstown
Jonestown
Annville
Palmyra
Hummelstown
Steelton
Highspire
Middletown
Mount Gretna
Elizabethville
Millersburg
Halifax
Dauphin
Duncannon
Newport
Mifflintown
Lewistown
Mount Union
Huntingdon
Shirleysburg
Mercersburg
Waynesboro
Greencastle
Chambersburg
Shippensburg
Newville
Carlisle
Mechanicsburg
Camp Hill
New Cumberland
Wormleysburg
Lemoyne
Enola
Marietta
Columbia
Manheim
Lititz
Ephrata
Denver
Adamstown
Ephrata
Lititz
Manheim
Columbia
Elizabethtown
Middletown
Hershey
Pottsville
Tamaqua
Shamokin
Mahanoy City
Ashland
Frackville
Shenandoah
Mount Carmel
Centralia
Minersville
Schuylkill Haven
Orwigsburg
Auburn
Tremont
Hamburg
Boyertown
Douglassville
Birdsboro
Kutztown
Fleetwood
Womelsdorf
Robesonia
Wernersville
Sinking Spring
Shillington
Mohnton
Wyomissing
Temple
Mount Penn
Lyons
Myerstown
Jonestown
Annville
Palmyra
Hummelstown
Steelton
Highspire
Middletown
Mount Gretna
Elizabethville
Millersburg
Halifax
Dauphin
Duncannon
Newport
Mifflintown
Lewistown
Mount Union
Huntingdon
Shirleysburg
Mercersburg
Waynesboro
Greencastle
Chambersburg
Shippensburg
Newville
Carlisle
Mechanicsburg
Camp Hill
New Cumberland
Wormleysburg
Lemoyne
Enola
Marietta
Columbia
Manheim
Lititz
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Denver
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general nature without minor details. The dissection has not advanced to the stage which characterizes the Schooley (Kittatinny) peneplain. On the Pocono Plateau and in the region north of the East Branch of the Susquehanna, it is very difficult to map the Harrisburg peneplain with any degree of accuracy. The most thoroughly peneplained surfaces are near the lower courses of the streams on the weakest rock, where the divides are lowered and first removed. Consequently in the upper courses of the streams the flood plains are narrower, the valley walls are steeper and the dissection has not advanced to the stage which characterizes the lower part. Even in a region which has progressed to the ultimate stage of the cycle of erosion it would be expected that the interior portion, near the headwaters of the streams, would be more irregular in character than the region in the lower courses of the streams. The map shows only that portion of the Harrisburg peneplain which can be mapped with a fair degree of accuracy.

THE SLOPE TOWARD THE STREAMS

In another publication[1] the writer has emphasized the fact that the Schooley (Kittatinny) peneplain slopes toward the streams. The notion that the Schooley (Kittatinny) surface was a flat one, with only faint undulations, must be abandoned. As has been pointed out, the valleys of the larger streams were two or three hundred feet below the highest divides and the surface was decidedly rolling. Even in the penultimate stage of the cycle of erosion, a peneplain surface may be quite irregular, even though the land is graded. The Harrisburg peneplain, like the Schooley (Kittatinny) surface, slopes everywhere toward the streams. The most pronounced slope is toward the Susquehanna which has been the major stream of the region since the beginning of the Schooley (Kittatinny) cycle of erosion or earlier. Is it not possible that an error may have been made in assuming that widespread warping of a peneplain has occurred, and that in reality the slope is simply the rise of the land surface, which necessarily is toward the headwaters of the streams and divides and is a normal feature? Since the slope of a peneplain may be pronounced toward the streams and toward the mouth,

[1] "Wind Gaps and Water Gaps of the Northern Appalachians, Their Characteristics and Significance," *Annals of the N.Y. Acad. of Sci.*, Vol. XXXII, pp. 87–220.

even in old age, it seems to the writer that what is interpreted as a result of warping may be a normal feature.

THE WARPING OF THE HARRISBURG PENEPLAIN

The question now arises as to whether the Harrisburg peneplain was warped when uplifted. Study of the Harrisburg surface has convinced the writer that it could have it present slope without any warping, the uplift being only a vertical one. Suppose that the Harrisburg peneplain with its widespread, well-developed, mature drainage system should be warped; what would be the result? The tendency would be for the streams to migrate toward the axis of uplift. Piracy on a grand scale would be the result, for some streams would possess the advantage of greater gradients. There should be evidence of piracy, such as wind gaps and barbed tributaries. Where streams have invaded other valleys by headward erosion we should expect to find barbed tributaries and valleys whose upper portions narrow down in the direction in which the streams flow.

The wind gaps of the northern Appalachians show by their elevations, which are almost all above the Harrisburg peneplain level, that the widespread warping of the Schooley (Kittatinny) peneplain may have been in large part responsible for the piracy which produced them. The absence of wind gaps below the Harrisburg level, however, seems to indicate little warping of that surface. Furthermore, no barbed tributaries or valleys which narrow down in the direction of stream flow could be found in eastern Pennsylvania. Surely, on a surface as well preserved as the Harrisburg, we should find some evidence in drainage changes that marked warping took place. If warping occurred at the time of uplift or since, we might expect to find evidence that the streams, the divides of which were established on the Harrisburg surface, had worked headward, encroaching on neighboring drainage basins. The writer examined the area carefully, seeking evidence of such encroachment. A number of maps embracing the area in the Great Valley and Ridge and Valley section of eastern Pennsylvania, where the peneplain is best developed, were carefully contoured. Everywhere, one finds that the slope of the peneplain is with the drainage, showing that if warping occurred it has nowhere been sufficient to reverse original slopes so as to make the upland peneplain surface (Harrisburg) out

of harmony with the slopes of the present streams. It would seem that the divides established on the Harrisburg peneplain have persisted to the present and no appreciable amount of shifting has taken place. A means of determining if warping did take place would be to compare the difference of elevation between the Harrisburg level and a lower peneplain surface. Since the Somerville erosion level is imperfectly developed and occurs only on the weaker rocks of the Great Valley, such a comparison is difficult. If it is assumed that widespread warping and tilting accompanied the uplift of the Harrisburg surface we must explain why such warping apparently has not been the cause of widespread wind-gap production, for the divides established on the Harrisburg peneplain have persisted to the present. The forces which produced the uplift in the Appalachians in the Ridge and Valley section of eastern Pennsylvania, since the development of the Schooley (Kittatinny) peneplain, were evidently not of the compression type like those which produced the Appalachian folds. There is sufficient evidence for the belief that warping accompanied the uplift of the Schooley (Kittatinny) peneplain and that these movements occurred during the Harrisburg cycle, but the evidence for the warping of the Harrisburg surface is not conclusive.

WHEN WERE THE WIND GAPS PRODUCED?

In order to determine the age of the wind gaps in the northern Appalachians it is necessary to consider their elevations. We find that the wind gaps everywhere lie above the Harrisburg level. We can assume that some of the broad, shallow wind gaps at the higher elevations were inherited from the Schooley (Kittatinny) cycle. It appears that almost all the wind gaps were produced during the Harrisburg cycle. It has been pointed out that the evidence shows that the divides established on the Harrisburg peneplain have not shifted and coincide with those at present. This is not in harmony with the theory of pronounced warping of the Harrisburg peneplain to the north and east as postulated. The fact that almost all the wind gaps have elevations above the Harrisburg surface seems to indicate that if warping is responsible for the piracy which produced the wind gaps, it must have occurred in post-Schooley (Kittatinny) and pre-Harrisburg and not post-Harrisburg time.

THE WARPING OF THE SCHOOLEY (KITTATINNY) PENEPLAIN

After the contour maps of the Schooley (Kittatinny) and Harrisburg peneplains were completed, it was possible to determine the amount of uplift that occurred at the inauguration of and during the Harrisburg cycle. A comparison of the difference in elevation should give one, with a fair degree of accuracy, not only the amount of uplift, but also the amount and direction of warping or tilting. It should be possible to determine whether the uplift during the Harrisburg cycle was vertical only, or accompanied by warping movements. The results of such comparison are shown on the following table which gives the distance in figures between the Schooley (Kittatinny) and Harrisburg peneplains in eastern Pennsylvania. The column on the left indicates the quadrangle and the one on the right the difference in feet between the Harrisburg and Schooley (Kittatinny) levels.

New Cumberland	800
Hummelstown	800– 900
Lebanon	800– 900
Wernersville	700– 800
Hamburg	700– 850
Wind Gap	750
Delaware Water Gap	750– 800
Wallpack	700– 800
Port Jervis	700– 800
Mercersburg	1,400
Shippensburg	1,400
Tyrone	1,200–1,300
Howard	1,000
Trout Run	1,100
Bedford	1,500
Huntingdon	1,200
Hollidaysburg	1,300

The outstanding feature is the increasing difference in elevation toward the north and west. The nature of the warping was such as to give a general southeastly tilt to the land. Contour maps of the Schooley (Kittatinny) and Harrisburg surfaces can have only a fair degree of accuracy and the author does not wish to imply that the figures are absolutely correct. It is difficult to draw contours across the remnants of the Schooley (Kittatinny) surface and in the case of the Harrisburg peneplain, in the region of the Pocono and Appalachian plateaus, it is equally difficult to trace the surface.

Hence the figures can only show the general nature of the warping. It is quite evident from the results obtained that there was a decided tilt of the Schooley (Kittatinny) peneplain to the southeast during the Harrisburg cycle. The evidence of the warping of the Schooley (Kittatinny) surface is in harmony with the results obtained by F. J. Wright[1] in the upper James River basin in Virginia. Several domes, loci, or axes of uplift have been mapped by Wright. Whether these are the result of warping, or are erosional in origin, would be difficult to determine. It is certain that on the Schooley (Kittatinny) peneplain there were broad, low swells or domes which are clearly the result of erosion. In eastern Pennsylvania occur rounded, dome-like monadnocks on the Schooley (Kittatinny) peneplain which are so located with relation to the streams, are so small in area, and of such shape, as to exclude the probability of warping as the explanation of their origin. They are more likely the result of erosion during the Schooley (Kittatinny) cycle.

CONCLUSIONS

Summarizing, it may be said that everywhere the Harrisburg peneplain slopes toward the streams. Hence it is quite possible that the rise of the Harrisburg surface to the north, west, and northeast may be, to a great extent, the normal rise of a peneplain without warping or tilting.

Evidence is lacking for widespread piracy in eastern Pennsylvania, as a result of the uplift of the Harrisburg peneplain. One would expect general piracy as a result of widespread upwarping of the Harrisburg surface to the north and east.

Wind-gap production took place mainly during the Harrisburg cycle as their elevations are everywhere above the Harrisburg level. Although it is not necessary to assume widespread warping to account for the piracy which produced the wind gaps, the fact that almost all the wind gaps were produced during the Harrisburg cycle may indicate that piracy was related to the warping which took place during that cycle. The uplift of the Harrisburg surface appears to have been, in eastern Pennsylvania, a vertical one unaccompanied by widespread warping.

[1] F. J. Wright, "The Physiography of the Upper James River Basin in Virginia," *Bull. 2, Va. Geol. Surv.* (1925).

REVIEWS

Carboniferous and Permian Spiriferids of China. By Y. T. Chao. Geological Survey of China, *Paleontologia Sinica*, Series B, Vol. XI, Fascicle 1. Peking, June, 1929. Pp. 133; pls. 11; text figs. 20.

In this important publication Yatsing Chao makes available further results of his elaborate studies of the late Paleozoic Brachiopoda of China. In it he describes the Spiriferidae with the same precision and skill which characterized his earlier work with the Chinese Productidae. He has recognized among the eight genera and forty-two species or varieties which he describes a new genus, twenty-eight new species, and three new varieties.

The new genus is *Tangshanella*, which is similar to *Brachythyris* in its internal structure, in its ovate outline, and in its short cardinal area, but which differs from it in possessing slender and commonly dichotomous plicae as well as very fine secondary radiating striae. The other genera appearing in Chao's collections are *Spirifer*, *Choristites*, *Munella*, *Brachythyris*, *Martinia*, *Squamularia*, and *Bracythyrina*.

Unfortunately the term *Munella* is a homonym without adjustment, the name having been preoccupied by Bonnier in 1896 for a crustacean. As a matter of fact, a new name for this group of shells, which Fredericks sought to distinguish from *Choristites*, probably is not needed, since it is doubtful if they actually are separable from that genus. The generic term *Brachythyrina*, though not included in Schuchert and Le Vene's new brachiopod Index, is correctly used instead of the more familiar *Anelasma* (which term is also a homonym); but there is some question as to whether *Brachythyrina* is not synonymous with *Fusella*.

Chao continues to include very detailed shell measurements of typical individuals of all species described, so that the foreign worker, even though he does not have access to the type specimens, can get from the descriptions sufficient data for the accurate comparison of related or conspecific material. Many of the specific descriptions are further illuminated by diagrammatic text figures. The plates are well made, and most of the species are portrayed by individuals shown in a number of different positions. In general, however, the plates in this publication do not

measure up to the *Palaeontologia Sinica* standard so far as clearness of reproduction is concerned.

A table showing the distribution and geologic range of the Chinese Upper Paleozoic Spiriferidae indicates that a number of the species have stratigraphic importance. Four species are known only from the Viséan Choniukan formation, 17 are confined to the Moscovian Penchi series of North China and Kansu, 4 are found only in the Upper Carboniferous Taiyuan series, and 10 are characteristics of the Permian system.

Chao's well-written report is marred by a rather large number of mistakes in spelling, which resulted from the fact that the publication went through the final stages of preparation while the author was in the field. The editors have inserted a page of errata in which the more obvious mistakes are corrected, but the worker using Chao's report as a reference must be on guard, particularly in reference to the spelling of specific and generic names.

CAREY CRONEIS

A Monograph of the Foraminiferal Family Polymorphinidae Recent and Fossil. By JOSEPH A. CUSHMAN and YOSHIAKA OZAWA. *Proceedings of the U.S. National Museum*, Vol. LXXVII, art. vi. Pp. 1–185; pls. 40.

The Polymorphinidae, like many of the groups of Foraminifera, have been in a state of great confusion either because many forms have been figured under the same name, or because many names have been applied to the same species. Cushman and Ozawa (Dr. Ozawa unfortunately died in Tokyo, December 29, 1929) after considerable study of types both in America and abroad, and after examining many thousands of mounted specimens from over a thousand localities, may be said to have clarified the situation admirably in the present monograph.

A few of the interesting discoveries regarding distribution are as follows: (1) Smooth, rather primitive species such as *Globulina gibba* and *Guttulina problema* are widely distributed and have a long geologic history. (2) On the other hand, the species of *Polymorphina* are restricted to narrow limits both at present and in the past. (3) Many areas have developed specialized species very restricted in their geographic distribution. (4) Pliocene and Recent faunas of Japan and southern California are closely related. (5) Oligocene species of Germany and upper Eocene forms from South Carolina are nearly identical. (6) The living fauna of the

Carolina coast and that of the Philippines are related, not in the shallow water species, but in those living at depths of more than one hundred fathoms. (7) The Trinidad Eocene species are similar to those now living in the Philippine region, and in general show Indo-Pacific relationships.

Cushman and Ozawa believe Paleozoic records of the family to be doubtful, but the Mesozoic representation of the Polymorphinidae is fairly good, especially from the Jurassic on; and the family is particularly common in the Tertiary and at present. The close relationship of the Polymorphinidae to the Lagenidae is discussed, and the phylogenetic relationships of the genera within the family are given considerable attention. There are also brief notes on the various generic names previously given to the Polymorphinidae, as well as descriptions of the clockwise and contra-clockwise coiling and fistulose outgrowths observed in this family. Incidental to the revision, three new genera, *Eoguttulina*, *Quadrulina*, and *Paleopolymorphina* are described and many new species erected. The numerous plates are well done though less effective than those with darker background which Cushman has been using recently in other publications.

Scientists the world over will be saddened by the fact that with the issuance of this monograph the successful paleontologic partnership of Cushman and Ozawa has been dissolved by death.

C. C.

Shallow-Water Foraminifera from the Channel Islands of Southern California. By JOSEPH A. CUSHMAN and WILLIAM W. VALENTINE. "Contributions from the Department of Geology of Stanford University," Vol. I, No. 1. Palo Alto, Calif.: Stanford University Press, 1930. Pp. 51; pls. 10.

The publication of this study of modern Foraminifera inaugurates auspiciously a serial for original papers by members of the staff and students of the department of geology at Stanford University. The new series is under the editorship of Eliot Blackwelder.

The initial paper describes a foraminiferal fauna collected from depths of 3–20 fathoms on the leeward side of a number of the Channel Islands of southern California. The fauna consists of 31 genera and 63 species, of which 12 species and 1 genus, *Dyocibicides*, are new. It was found that the Foraminifera from similar environments, though different localities, were uniform, but that in the same bay the Miliolidae, for example, are likely to

be abundant on one side and rare or absent on the other. The fauna is most closely related to that of the west coast of South America, but some species are of the West Indies type, and a few are derived from colder regions and are thus related to those of Northern Europe. In addition, a number of the forms are conspecific with those found in the late Tertiary sediments of California.

The plates, which are composed of light figures on a black background instead of the reverse, seem to be more satisfactory than the older type.

C. C.

Ecological Relations of Some Foraminifera. By RICHARD D. NORTON. *Bulletin of the Scripps Institution of Oceanography, La Jolla, California.* Technical Series, Vol. II, No. 9. Pp. 331–88.

This is a relatively short but nevertheless important article dealing with a subject which has thus far received all too little attention. Although Norton gives some information regarding the ecology of thirty-four of the forty-four families of Foraminifera recognized by Cushman in his revision, the article's chief significance lies in its demonstration of the desirability of more elaborate studies in the same field. Worthwhile features of the present publication include a number of useful figures and tables, a list of species rather closely confined to zones A and B (0 to 60 fathoms), and a serviceable Bibliography. The more important conclusions are as follows:

(1) In zone A, from 0 to 5 fathoms, with a temperature range of 21° to 32° C, the Miliolidae and Peneroplidae are generally abundant. In more restricted areas of this zone the Valvulinidae, Calcarinidae, Homotremidae, and Nonionidae may be rather common.

(2) In zone B, from 5 to 60 fathoms, with a temperature range of 20° to 31° C, there is a marked decrease in the Miliolidae and Peneroplidae representation, but the Lagenidae, Textulariidae, Buliminidae, and Amphisteginidae are likely to be common.

(3) In zones C and D, from 500 to 2,850 fathoms, with temperature range of 2° to 8° C, the Globigerinidae and Globorotalidae predominate.

(4) The Lagenidae and Buliminidae persist to great depths, but in small numbers.

(5) The Rotaliidae and Anomalinidae are without definite ecological value since they are rather uniformly present at nearly all depths.

C. C.

Gefügekunde der Gesteine. By BRUNO SANDER, University of Innsbruck; Wien: Julius Springer, 1930. Pp. 352; figs. 155; structural diagrams, 245. M. 37.60 unbound, M. 39.60 bound.

This book takes up some of the mathematical and physical aspects of structural geology in a manner not yet attempted in an English publication. The author has no hesitancy in plunging the reader into calculus, petrography, or any branch of science which will aid in solving the problems of rock deformation.

Excellent use is made of the strain ellipsoid which the author is careful to treat in three dimensions. Particularly interesting are its applications on the flanks of folds revealing the progressive changes in position and shape with the progress of deformation. These are well brought out by a series of experimental models; discussions of practical applications follow.

Structural relations of single minerals are studied—some are more resistant to deformation than others and an attempt is made to evaluate these differences and to carry them over into rock types. The rotation of individual mineral grains in the production of structures has been investigated and it is shown that some grains change position with almost no internal deformation while their neighbors are considerably deformed.

The book is profusely illustrated and the pictures and diagrams will be useful to a geologist without a command of German. A Bibliography of 118 references concludes the work.

J. T. McC.

Ingenieurgeologie. By K. A. REDLICH, Prag; K. v. TERZAGHI, Cambridge Tech.; and R. KAMPE, Prag. Wien and Berlin: Julius Springer, 1929. Pp. 707; figs. 417.

Engineering geology is a fitting title for this book; the authors present concisely the information regarding geology which is essential to most branches of engineering. Historical geology is omitted and physiography cut to a minimum, but there is a comprehensive study of rocks and minerals placing most stress on the qualities necessary for an ore or a building stone. Structural geology is presented particularly from the standpoint of strength of materials. Sanitary engineering and other water problems are treated from the geologic point of view. Mapping and conventional symbols are discussed in sufficient detail to enable the engineer to make good use of a comprehensive geologic report. Some space is devoted to seismology and its various applications, and considerable attention is given to the geological aspects of highway engineering.

J. T. McC.

Baltimore County, Maryland Geological Survey. Baltimore: Johns Hopkins Press. Pp. 415; maps in separate cover.

Among the nine contributions in the Baltimore County report is a noteworthy paper by Eleanora Bliss Knopf on the physiography of this area and the region in general. Most attention is given to the Pleistocene features and the term "terraces" is used for what have frequently been called "peneplains" in previous reports; the usage in this paper seems much more in accordance with the facts. New evidence regarding the identification and correlation of these terraces and their relation to the Cretaceous peneplain is brought out. This paper contains an excellent colored map showing the distribution of these terraces, a correlation chart, and numerous good illustrations.

J. T. McC.

The Earth for Sam. By W. MAXWELL REED. New York: Harcourt, Brace & Co. Pp. 387. $3.50.

In this day of "outlines" of history, science, religion, etc., this form of presentation has grown commonplace, but here is a book of that general type which stands out for its freshness of presentation and accuracy. Fortunately the author presents, in an impartial manner, the several sides of many of the debatable questions, and dogmatic statements are not forced on the reader. The book is written expressly for youngsters, but the manner of presentation makes it interesting also for the more advanced; the facts are there, presented simply and often humorously. A layman will derive sound fundamental knowledge of earth-science from reading this book.

Physiography, historical geology, economic geology, structural geology, and paleontology are interwoven skilfully in a fascinating story and throughout this tale the author has been careful to answer the "why?" always raised by children. The copious illustrations deserve special mention; they stress paleontology—which is of most interest to the average reader—and they amplify the text very effectively.

J. T. McC.

The Upper Cretaceous Formations of Southwestern Arkansas. By CARL H. DANE. *Arkansas Geological Survey, Bulletin 1* (1929). Pp. 215; pl. 29; and geologic map in colors.

A long-needed piece of work is that of deciphering the stratigraphy of southwestern Arkansas and making careful correlations with neighbor-

ing areas. No detailed investigation of this area has been made since the work of Hill and Veatch, twenty-five years ago. The lack of extensive outcrops and the intricate nature of the stratigraphy have caused geologists to make tentative correlations from limited study, or to shun the area entirely. Much credit is due the author of this new report for placing this phase of Arkansas geology on a "working basis."

Topography, stratigraphy, structural conditions, paleontology, etc., are all covered. Conditions of deposition are inferred from the characteristics of the sediments and their faunas. A number of hitherto unrecognized local disconformities, or "breaks" as they are called, have been definitely established. Many formations have been subdivided and redefined according to new interpretations. Fairly complete faunal lists are given with many excellent plates of typical and diagnostic species. For the petroleum geologist, the seventy-odd wells drilled within the area have been located, the limits of the formations penetrated defined, and correlations postulated. The geologic map is on a small scale, but sufficiently accurate for most work.

R. E. E.

Geologic Map of Arkansas. By G. C. BRANNER. Issued by the Arkansas Geological Survey in co-operation with the U.S.G.S. Scale, 1:500,000 or about 8 miles to the inch. Price $1.80 postpaid.

The map is of unusual merit due to its arrangement and introduction of new features. Economic data such as mines, quarries, oil and gas fields, pipe lines, etc., the axes of the anticlines in the Arkansas River Valley province, and the physiographic divisions of the state shown upon a small scale map in the legend, add greatly to its usefulness without detracting from its general appearance. Separate geologic columns with the corresponding symbols for the formations are given for the major divisions of the state, thus permitting of great detail in each case. The map is the result of the compilation of the work of many geologists, each possessing an intimate knowledge of a certain portion of the state. Probably the work of H. D. Miser deserves mention as the single greatest contribution to its success.

R. E. E.

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